

SCIENCE
IN MODERN LIFE

SCIENCE IN · MODERN · LIFE

A SURVEY OF SCIENTIFIC DEVELOPMENT
DISCOVERY AND INVENTION AND THEIR
RELATIONS TO HUMAN PROGRESS AND
INDUSTRY

PREPARED UNDER THE EDITORSHIP OF

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PHYSICS

(Continued)

CHAPTER V

SOUND

SOUND WAVES.—The waves of sound, as has already been stated, consist of to-and-fro motions of the molecules of the air in the line along which the sound is travelling, constituting longitudinal waves of compression and rarefaction. These travel with the speed appropriate to the elasticity and density of the air, about 1100 ft. per second. This speed is the same whatever the lengths of the waves, but very violent disturbances, the sounds of an explosion or a volcanic outburst, may travel at a greater speed than this, up to 2000 ft. per second. They only do this by profoundly modifying the properties of the air they are disturbing. The violent heating brought about by the compression, which occurs too suddenly to admit of any equalization by conduction, causes an increase of the velocity, for sound travels faster in hot air than in cold.

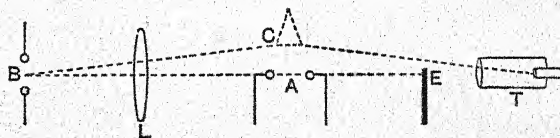


Fig. 85.—Visibility of Sound-waves

TÖPLER'S METHOD.—Sound waves can be made visible through the slight disturbances their passage causes in the optical transparency of the air. Light passing into a belt of air, however small, of density greater or less than the average, is refracted, and the rays passing to the eye reveal the inequalities by a bright band. Töpler used the sound wave sent out by the "crack" of an electric spark A (fig. 85). The light of the spark itself was screened from the eye, but the air waves, illuminated by a second spark, were rendered visible by a most ingenious device. A screen E was so placed that its edge just cut off the light of this second spark also from

the telescope T. It will be seen that a prism placed as represented by the dotted lines at C will bring the light of spark B to the telescope, and the same result occurs if instead of a prism we have a mass of air at C which is denser on the side nearer A. So when a sound wave sent out by A reaches the spot C, the light from B reaches the telescope. The same occurs for all points along the wave anywhere near C, so the outline of the sound wave is indicated by a bright curve in the field of view of the telescope. The spark B has to be so arranged as to follow that of A after the lapse of a very small fraction of a second.

Professor R. W. Wood has substituted a sensitized plate for the telescope, and so photographed the waves. He has shown them after reflection by mirrors and refraction by prisms and lenses made of thin collodion films inflated by carbon dioxide.

ORIGIN OF SOUND WAVES.—Sound waves are set up by the vibrations of bodies as a whole, not by molecular vibrations. Thus, to take a simple case, the prong of a tuning fork swinging to and fro exercises first a push upon the air beside it, and then withdraws, leaving a partial vacuum behind. In the push the air is compressed, and, since a gas is elastic, a condensation wave is sent out in all directions. As the prong moves back, the air particles round about rush in to fill the vacuum and become themselves rarefied. Hence a rarefaction pulse follows upon the condensation, and such a wave is repeated at each complete swing of the prong.

QUALITIES OF SOUND WAVES.—Sound waves as perceived by the ear differ in loudness, in pitch, and in quality or timbre. Sound waves as existing in the air differ in the extent or amplitude, in the quickness or frequency, and in the form of the vibrations which produce them. These differences are the keys to the variety of our perceptions. If the vibrations are large and powerful, if our tuning-fork prongs are swinging through a considerable distance, then we hear a loud note. If the fork has thick short springy prongs vibrating rapidly we hear a high note. To obtain a note differing in timbre from that of the fork, we must use some other instrument whose vibrations are of different form. A tuning-fork prong swings to and fro very much in the manner of a pendulum bob, performing simple harmonic motion. Violin or piano strings, on the other hand, vibrate in much more complex fashion, and so do the columns of air in organ pipes.

GRAPHIC REPRESENTATION OF SOUND WAVES.—If we photograph a bright speck on the prong of our tuning fork upon a plate moving rapidly and uniformly at right angles to the direction of the vibrations we find a wavy line of form a , but in the case of a violin string the shape

is rather that of b . Now mathematical analysis shows that b can be built up of a number of curves of the form of a , for instance by such as those in c . It thus appears that the note of the violin is really complex, being made up of the lowest tone, that of the tuning fork of the same pitch, one three times as short and three times as rapid in its vibrations, another five times as quick, and so on.

RESONANCE.—Helmholtz, by a remarkable analysis of such complex notes, was able to prove that this really is the case. He employed the principle of resonance, which assumes, perhaps, its most important place in sound. Whenever air waves find a body ready to vibrate at the same rate as themselves their energy sets the body in vibration, and it sounds its own natural note, the same as that which set up the waves. This is the effect known as resonance. The air in a hollow vessel has a natural time of vibration and gives a particular note of that frequency and no other. The singing of gas globes often heard when one particular note is played on a pianoforte in the room is an instance of the kind; no other note is able to make the globe resound.

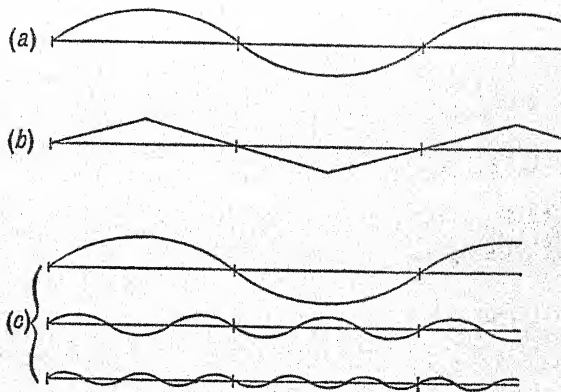


Fig. 86.—Forms of Vibrations

When a violin string is bowed near a system of air vessels, resonators, of different sizes, each sings its own especial note, if that frequency is included in the waves from the string, but not otherwise. Consequently we can analyse the note of the violin by listening for the resonators which answer it, and those for a string bowed at the middle are exactly those above mentioned.

The lowest or **FUNDAMENTAL TONE** fixes the pitch of the string, the presence of the others, the overtones, gives the distinctive quality which we call violin timbre, so brilliant and so unlike the spiritless smooth tone of a tuning fork. Practically all instruments have such overtones in varying numbers and degrees of loudness, and thus can be distinguished from each other by ear.

OVERTONES.—The flute, almost free from overtones, has nearly the

same quality as a tuning fork. Every change in the form of a tube brings out overtones in great variety—oboes, horns, trumpets, cornets, trombones, saxophones, all are merely mouth-blown organ pipes of special shapes, whose lengths can be varied to alter the frequency, *i.e.* the pitch, either by a sliding part, as in the trombone, or by the opening or closing of side apertures in the rest.

Even the alteration of form of the resonator alone may alter the timbre by reinforcing different overtones produced in the vibrations. Thus the violin tribe all emit their notes by means of similarly bowed strings, yet compare the passionate tones of the 'cello with the brighter excitement of the violin and the more restrained melodiousness of the viola.

All these instruments obtain their wonderful diversity of tone merely by ringing the changes upon a certain few overtones, the notes of frequencies twice, three times, four times, &c., that of the fundamental.

A somewhat different case is that of such PERCUSSION INSTRUMENTS as drums and cymbals; we seem able to detect a lack of regularity in their rougher notes. Analysis by resonators bears this out, showing that the overtones are not such definite multiples of the chief note, but more irregularly distributed above it. Occasionally the fundamental is weak in comparison with the overtones; in English bells it is the fifth note of the series, *i.e.* the fourth overtone, which fixes the apparent pitch of the note. The lower tones furnish the characteristic depth of the bell, extending as much as two octaves below the predominant note.

The CONDITIONS FOR RESONANCE, which become of extreme practical importance in wireless telegraphy, can be easily studied in sound. To cause a body to resound, the waves which fall upon it must continue their pushes and pulls for a considerable number of swings, or they will not be able to set the body vibrating to any appreciable extent. Take the case of two tuning forks of the same pitch mounted upon sounding boxes. If one is bowed or struck the other begins to sound also, but if the first is almost instantly stopped the note of the second is very weak. Thus such a vibrator as a stretched string without a sound board cannot set up much resonance in a fork of the same pitch, because the string's vibrations are much "damped", *i.e.* die away rapidly. The curves it would give on a moving photographic plate (corresponding to those of fig. 86 *a*) are of constantly lessening extent, like fig. 87.

Again, the resounding body must have particular qualities. If it can vibrate in a great many ways it will resound to a great many notes; for instance, a piano with the loud pedal held down will sing back any note that is sung into it. On the other hand, a tuning fork will only answer

to its own particular note, *i.e.* to the one of the same frequency as its own.

STRUCTURE OF EAR.—What mechanism is it which allows the ear to detect all the changes in pitch and quality which are presented to it by such a complicated sound as that of a band? The ear is a sensitive resonator; the air waves set the drum or tympanum vibrating, and the disturbance is thus introduced to the cochlea or inner ear and plays upon a number of threads, Corti's fibres, attached to a membrane to which the nerve endings are also affixed. The drum vibrates in answer to any source of sound in the same periods as those of the sounds themselves. From the complex tremors thus passed on, the fibres select each its own vibration and act as resonators.

Thus a tuning fork affects but one set of fibres, but a violin string

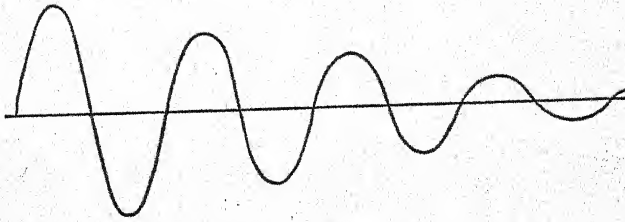


Fig. 87.—Damped Vibrations

excites also those of 3, 5... times the rapidity of vibration, an open organ pipe those of all multiples, odd and even, up to a certain number.

What again will happen if two notes reach the ear at the same time, not of exactly the same pitch but so close together that they affect the same fibres? The fibres will vibrate, but after a very short time the swings of one wave will be opposed to those of the other and the fibres will stop. Then the waves come back gradually into step again, and so we observe alternate sound and silence, the phenomenon known as beats. The closer together the notes are the longer does it take for one to gain a wave on the other, and so the slower become the beats.

THE VOICE.—The voice is produced by a sort of organ pipe, the larynx acting as the reed of the pipe, the throat and mouth cavities as its resonators, which can be varied in size and shape, altering the pitch and quality of the sounds.

REGISTERS.—The difference in quality of the falsetto and chest registers has lately been the subject of research, and photographs have been obtained of the vibrations of the larynx in each case by what is called the **STROBOSCOPIC METHOD**. The larynx is illuminated intermit-

tently by a beam of light passing through a number of holes in a rotating disc. The speed of the disc is varied until a flash passes once for each vibration of the larynx. Hence the latter is always in the same position when illuminated, and what is practically a time exposure can be made without blurring on the photographic plate. Successive pictures can be made of each stage in its motion, and comparison of these, or direct examination by the laryngoscope thus illuminated, reveals the process of vibration. The main conclusion arrived at is that the mode of vibration in the chest register is quite different from that in the falsetto. In the former the larynx swings to and fro like two plates fixed each at one edge (A, fig. 88, which shows in cross section the extreme dotted curves and middle straight-line positions of the membranes). In the falsetto the edges of the larynx near the central slit remain comparatively still; it

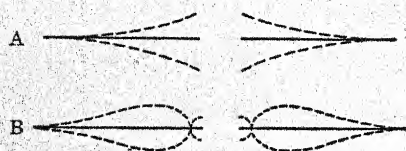


Fig 88. — Vibrations of the Larynx

is the central portion of each plate which swings to and fro more after the fashion of B.

PHONOGRAPH.—The audible reproduction of music, and especially of the sound of the human voice, by mechanical means, has been the subject

of much labour, which has reached its greatest success in Edison's PHONOGRAPH. In the early form shown, the cylinder, rotated steadily by means of the handle, moves also lengthwise under the action of a screw. The disc, of thin glass, has at its centre a sharp point, just visible in the photograph, which when set in position just presses upon the surface of rather thick lead foil wrapped round the cylinder. The disc catches the sound waves in the air and vibrates in the form they take (like the drum of the ear), characteristic of the vibrations producing them. Thus the style is caused to impress more or less deep indentations on the lead paper. The form of these of course depends on the vibration of the disc. The handle is turned at a constant speed, so no two indentations fall at the same place, but a record of pin pricks is traced in a spiral around the advancing cylinder. If at any subsequent time the instrument is set exactly as at first, and the handle turned as before, the series of indentations passing below the style push it up and down in precisely the same manner as did the original sound waves. The disc reproduces its previous movements and sends out identical though weaker air waves, thus "playing the tune" over again.

Later models are the same in principle but have adopted a clockwork motor to secure steady and automatic running, and have replaced the lead

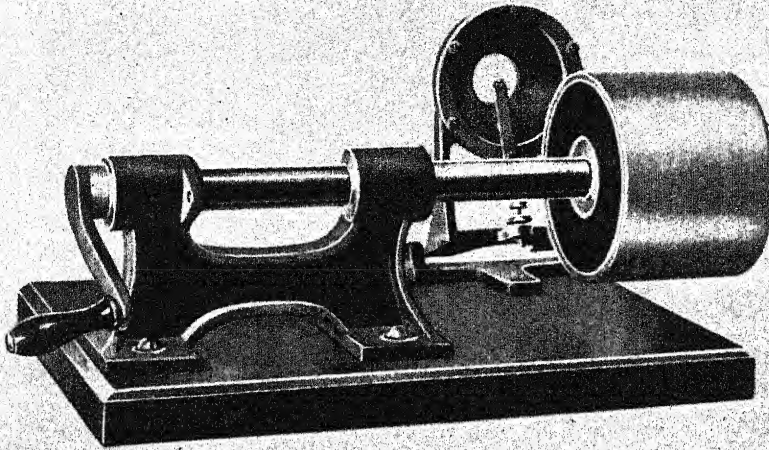


Fig. 89.—Edison's Phonograph

foil by a fine wax cylinder upon which the sharp style forms the impressions. A round pin takes the place of the point in reproducing the vibrations. In the GRAMOPHONE a disc is used instead of the cylinder, and wave forms are similarly traced out in a spiral upon its flat surface.

CHAPTER VI

LIGHT

SPEED OF LIGHT.—Light is propagated with a speed of 186,000 miles per second, or, in other words, takes about eight minutes to reach the earth from the sun.

WAVES OF LIGHT.—Its reflection from smooth objects, transparent or opaque—its bending or refraction in passing from one transparent medium to another of different density—the phenomena of interference and diffraction—all show its passage to be that of a wave motion. The medium in which the waves travel is not air, for they traverse the air-free space from sun or stars to the earth with slightly greater speed than in air itself, and can also penetrate transparent bodies, at speeds usually less than in air.

NATURE OF LIGHT WAVES.—The waves are not longitudinal as in sound, but rather resemble sea waves, in which the motion of the vibrating particles is perpendicular to the direction of travel of the waves. In other words, the vibrations in a light wave are TRANSVERSE, as is shown by a certain two-sidedness produced in some circumstances and known as POLARIZATION.

THE ETHER.—It is in fact the ether, which here we need to introduce for the first time, which carries these waves, as also those of electric disturbance, of which we shall later on find that light waves are but a special case.

It may seem that in the present work but little mention is made of the ether, and that its place in the universe appears but secondary and unimportant in relation to that of matter. In reality the ether is necessary to an explanation of the universe, not in any subordinate degree but as a fundamental entity, without which we can give no rational or exact account of the processes of light, electro-magnetism, gravitation, even perhaps of the existence of matter itself. The ether permeates all space, whether already apparently occupied by matter or not, as much in lead or rocks or air as in the "free space" between the stars. It must allow of the passage of matter through itself without friction, or we should have a slowing down of the motions of the heavenly bodies, as when a feather falls through the air, or a weight is thrown into a treacly liquid. In other words, the ether cannot be viscous. Older views regarded it as an elastic solid in order to explain the possibility of the existence in it of transverse vibrations. Such solidity is extraordinarily hard to reconcile with the ultra-perfect fluidity above demanded, and Lord Kelvin has shown that a liquid free from viscosity, whose parts were in incessant motion resembling those of vortex rings, possesses, purely in virtue of these motions, a quasi-rigidity which would enable it to transmit transverse waves, at the same time keeping all its fluid properties. This is the "gyrostatic" rigidity we have noticed in a spinning top (Vol. II, p. 158). Such an ether, then, has the properties required to allow it to transmit wave motions, and at the same time to oppose no resistance to the steadily moving planets, and the mathematical researches of Larmor and others permit us to consider matter as local modifications of the ether itself. To put one view of the subject as briefly as possible, the ether is not itself material, but its properties may be so modified in special minute regions that the properties of inertia and the other characteristics of matter may be produced.

ELECTRONS.—We shall see reason later for supposing that the smallest

constituent parts of all substance are the ELECTRONS, and that collections of these in varying numbers and arrangements make up the ATOMS of the chemist. The electrons then are these local modifications of the ether, not precisely matter themselves, but forming the bricks of which is built the atom, itself a constituent of ordinary matter in bulk. The electron, being but modified ether, should have the same density, *i.e.* the same amount of inertia per cubic inch, as the ether itself. Now the electron is an extremely dense thing, having inertia to the amount of about 33,000,000 tons per cubic inch. Hence Sir Oliver Lodge reaches the astonishing conclusion that this enormous figure represents the density of the ether, about 2 billion times greater than that of water. To put it in another way: if we could reduce its density by some method of exhaustion in the same proportion as the density of the heaviest metal bears to that of the rarefied gas in the best vacuum of an X-ray tube, that final density would still be greater than the metal's. Lodge points out that this vast density in itself presents no difficulty, for the ether does not gravitate like matter, and great density is in no way incompatible with small viscosity—the resistance of a fluid to the motion of a body through it does not bear any direct relation to the density; thus quicksilver is far less viscous than treacle though ten times as dense.

REFLECTION OF LIGHT.—To return to the properties of these ether waves which bring us the sensation of light, we find reflection as an everyday phenomenon, too obvious to need illustration, though a few instances may indicate the method more clearly.

CONCAVE MIRRORS are often used to direct a beam of light, and the form of the wave fronts depends greatly on the shape of the mirror. With a parabolic one and a source of light at its focus, the waves pass off with plane front, the light neither converging nor scattering, but always covering the same "frontage"; hence the suitability of the parabolic mirror for SEARCHLIGHTS.

Such a mirror as a silvered hemispherical finger bowl gives much more complicated waves from a light source in a corresponding position,

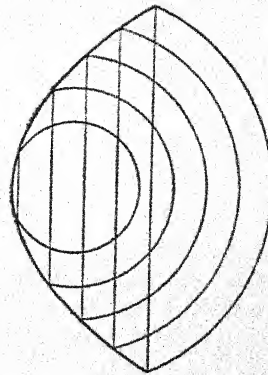


Fig. 90.—Parabolic Mirror

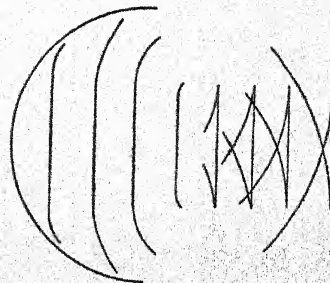


Fig. 91.—Hemispherical Mirror

though the central parts, as will be seen (fig. 91), are still very nearly plane. (The direct light, the arcs of circles of fig. 90, are in this case omitted for the sake of clearness.) At one position, that of the fourth wave front shown, the curved parts of the waves have condensed to a focus, so that a sheet of paper placed there shows a ring of light with comparative darkness within and without.

REFRACTION OF LIGHT.—This phenomenon occurs, for instance, when light passes from air into water. In the denser medium the waves go more slowly than in air, so we find them bent as shown in fig. 92.

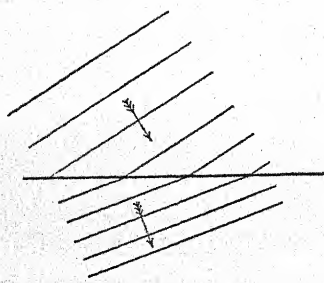


Fig. 92.—Refraction

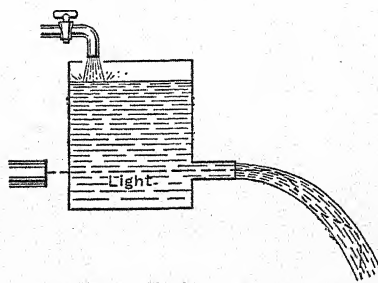


Fig. 93.—Total Internal Reflection

Reversing the arrows, we illustrate the passage from water into air. If the angle the wave front makes with the surface is so great that the light emerging only just skims along the surface, then any increase of the angle beyond this "critical" value altogether prevents the escape of the light, which is simply turned or reflected back into the water.

This **TOTAL REFLECTION** is prettily shown by throwing a narrow beam of light in the direction of the flow into a jet of water escaping from a wide nozzle in the side of a glass vessel.

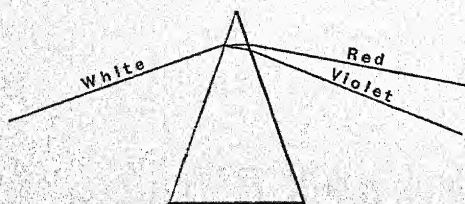


Fig. 94.—Dispersion by a Prism

The jet curves downwards in the form of a parabola, and the light's wave front never makes less than the critical angle with the surface of the water, and so is reflected and re-reflected from side to side.

Thus the jet appears luminous, especially at the point where it breaks up into drops. The general direction of the beam is indicated by the dotted line in diagram 93.

THE SPECTRUM.—When a beam of white light passes through a glass prism it is split up into the **SPECTRUM** or rainbow colours, showing that white light is really compounded of these coloured beams, and that the different colours are refracted by the glass to varying extents. In other

words, the change of speed of the waves is different for different colours; the violet is most bent, then the blue, green, yellow, and red in order, showing that this is also the order of velocities of light waves in glass, the red being the fastest.

DISPERSION.—This separation by refraction of white light into its coloured parts is called dispersion, and may be the source of much trouble in lenses by blurring the edges of objects, as viewed through the glass, with a coloured fringe.

ACHROMATISM.—This colouring is avoided, or, as we say, achromatism is secured, by using a **COMPOUND LENS**. Take the case of a photographic lens. If it is not corrected, the focus for the rays which make the picture is different from that of the rays which are observed by eye on

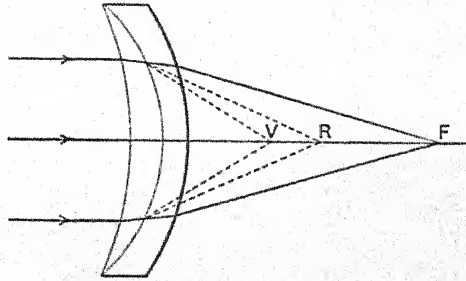


Fig. 95.—Compound Lens

the ground-glass back of the camera, so that with such simple lenses the plateholder has to be racked in a little after focusing. The use of a compound lens avoids this. Fig. 95 shows a common type of corrected single lens built up of two parts, the left-hand side of the diagram facing the view to be photographed.

The convex lens made of crown glass would bend the rays of light as shown by the dotted lines, the violet end of the spectrum bending most to V, while the red would be focused at R. The photographically active rays would be focused even nearer the lens than V.

But these separated rays have to traverse also the concave lens, made of flint glass, which also refracts the violet more than the red; this time the thickest part of the lens is around its circumference, so that the total bending is less

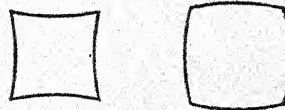


Fig. 96.—Distortion of Field

than that of the convex lens alone, and the rays are focused farther away than to V or R. If the two lenses are chosen to suit each other, the convex may be stronger than the concave, so that the light is focused by the pair, and yet the dispersion of the denser flint glass may just balance that of the crown, so that both the violet and red rays are diverted to the same focus F.

DISTORTION.—But there are other faults in the refraction of an ordinary lens still uncorrected: such a single lens does not throw a square image of a square object, but turns it into the shapes shown, according as

the "stop", *i.e.* the aperture limiting the width of the beam, is behind or in front of the lens. This DISTORTION is avoided by the use of a RECTILINEAR LENS, in which we have two lenses (each an achromatic pair), one in front of and the other behind the stop. Thus the cushion form which the outer alone would produce is corrected by the tendency of the other to throw a barrel-shaped image.



Fig. 97.—Rectilinear Lens

ASTIGMATISM.—Even a rectilinear lens, however, usually focuses differently in the two directions; that is to say, if the horizontal lines of a picture are sharp the vertical ones are more or less fuzzy, and vice versa. This defect is ASTIGMATISM, and results from the stronger refraction of the glass in one plane than in the other. An extreme case would be that of the cylindrical lens (fig. 98), in which all the refraction is in a horizontal direction, so that a bright point would be focused as a vertical line. In the lens of our camera, of course, nothing so pronounced as this takes place, but there is some astigmatism. It results not from the choice of shape and arrangement of the lens, but from the material of the glass itself. It is obviated in ANASTIGMATIC LENSES by the use of special glass which possesses a perfectly uniform structure; such lenses are, of course, more expensive. Stopping down a lens is beneficial in cases of astigmatism, but has no effect on distortion.

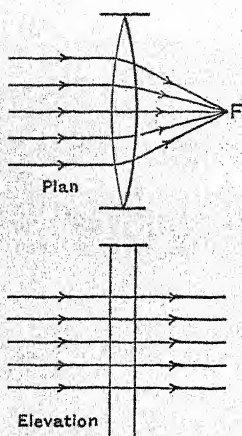


Fig. 98.—Cylindrical Lens

CURVATURE OF FIELD.—Two other defects are sometimes confused by the amateur; they are also both obviated by stopping down. One is a curvature of the field, causing the outer portions of a picture to be focused a little nearer the lens than the central part. So in a group photograph the outer members are usually brought a little forward.

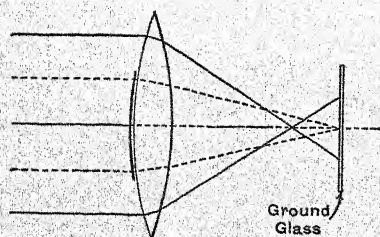


Fig. 99.—Spherical Aberration

SPHERICAL ABERRATION.—Spherical aberration is the other error which also prevents good definition with a wide aperture. It is a property of an ordinary spherical-surfaced lens that the outer part has shorter focal length than the centre, so that if we stop the lens down and focus some small object sharply the definition is not so

aperture. It is a property of an ordinary spherical-surfaced lens that the outer part has shorter focal length than the centre, so that if we stop the lens down and focus some small object sharply the definition is not so

good with a wider stop, and still worse if the middle part of the lens is covered by a small bit of paper and only the outer exposed ring of glass employed. The central rays by which the picture was focused are shown in fig. 99 as dotted lines, those from the outer region as full lines.

The "FLARE SPOT" which sometimes puts a bright patch in the middle of a print is due to light reflected from the surface of the inner lens, re-reflected by the outer one, and so reaching the plate.

CHAPTER VII

SPECTROSCOPY

COLOUR EXPERIMENTS OF R. W. WOOD.—The phenomenon of colour is always pleasing; let us attempt in this and following chapters to describe a few experiments which illustrate by colour effects the chief further principles of the science of light. Most of these are due to the experimental genius of Professor R. W. Wood of the Johns Hopkins University. We saw that a substance refracts light variously according to its colour, and experiments based on interference effects show that the explanation of colour differences lies in the wave length of the particular light. The waves constituting red light are longer than those of yellow, and the series proceeds through green and blue to violet, the shortest waves perceived by the eye. Thus we may express the facts of refraction and dispersion, generally speaking, by saying that on entering a denser medium the speed of light waves is decreased, and the decrease is most marked in the case of the shorter waves.

It is possible to make a mixture of the two colourless liquids carbon bisulphide and benzol in which the speed is the same as in glass. Accordingly light passing through powdered glass in such a solution is not refracted or disturbed in any way; the glass should therefore be invisible. This is possible for light of a single colour, say the light of a flame tinted yellow by common salt; but the speed is different for various colours, so that if we use ordinary white light, its red and green and blue constituents are refracted and scattered by the particles of glass, only the yellow passing straight through. Wood recommends a pasty mass of the glass and liquid in a sealed flask, the liquid so arranged by trial that at the ordinary temperature only red light gets through; then, on slightly and unevenly warming the flask, the refraction is somewhat changed, and other colours burst out, "the whole appearing like a great opal".

SPECTROSCOPE.—The spectrum or fan of coloured lights into which white light is opened out when “dispersed” by a glass prism is most readily studied by the apparatus known as a **SPECTROSCOPE** or **SPECTROMETER** (fig. 100). Light from an appropriate flame **F** (fig. 101) shines through a narrow slit upon a lens **L** at the opposite end of the metal tube **C**,

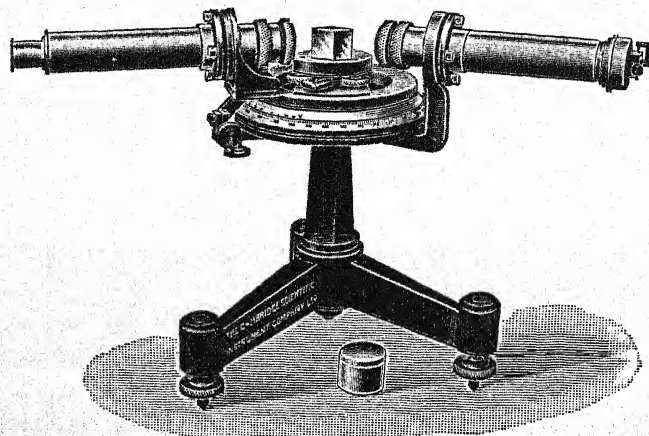


Fig. 100.—Spectroscope

the **COLLIMATOR**. This lens collects the rays spreading from the slit and passes them on as a parallel-sided beam to the prism, which refracts them, and in so doing splits their whiteness into the rainbow hues. The light thus separated is examined through a telescope **T**, which is focused so as to show a sharp band coloured in ordinary cases with the rainbow tints in order—red, orange, yellow, green, blue, violet; the last named

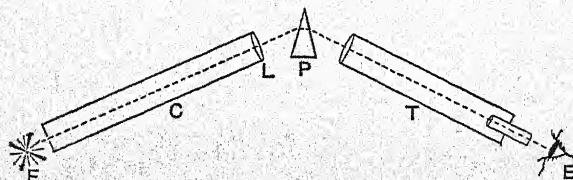


Fig. 101.—Principle of the Spectroscope

being most bent from the original direction of the white ray in the collimator.

The science of spectroscopy has already been treated in some of its larger aspects in the section of this work on Chemistry.

CONTINUOUS SPECTRUM.—Spectra, it may here be added, are of several kinds. There is the **CONTINUOUS SPECTRUM** afforded by the white light emitted by white-hot bodies, bodies, that is, which are so

strongly heated that their intramolecular vibrations include all the rates which produce waves detectable by the eye. The shortest of these appear last, during the process of heating up the glowing body.

SPECTRA OF VAPOURS.—Glowing vapours, especially metallic vapours, yield spectra of quite another kind. Only a certain limited and definite number of methods of vibration seem open to such bodies; so they emit light of correspondingly definite wave lengths. Thus sodium vapour produced by fusing a small bead of soda in a Bunsen flame emits an intense yellow light, and the spectrum of this light is also yellow, showing two narrow bright lines, quite close together, in what would be the yellow part of the continuous spectrum of such a glowing solid as a piece of platinum heated white-hot in the gas flame. The light sent out by sodium vapour in fact is almost all one colour, this vivid yellow, and has a wave length of about $\frac{1}{10000}$ millimetre.

So, again, strontium vapour gives a beautiful crimson hue to the flame, and its spectrum reveals several red and orange lines and one bright-blue one.

Such lines as these are quite narrow, showing that the light of each is practically of one wave length only, and therefore of one colour, "monochromatic". Gases, such as hydrogen or nitrogen, heated to the point of glowing, or caused to radiate light by the passage of an electric discharge through them in a vacuum tube (see below), display similar spectra.

Thus vapours, vibrating more simply and uniformly than heated solids, betray this simplicity in the light they emit. Each has its own particular rate of molecular vibration, and sends out light waves of the same frequency through the ether.

Chemical or electrical actions of some kind are doubtless the cause of the vibrations of the electrons which produce the light in these line spectra. For mere heating, however intense, in a closed vessel cannot make a vapour glow, and yet the temperature in a Bunsen flame is not very high, while that in a vacuum tube is quite low.

RESONANT VIBRATION—ABSORPTION LINES.—Now we have learnt that a body which can vibrate in a definite way will be set into such vibration when waves of the appropriate quickness fall upon it, and in the process absorbs those waves. This is **RESONANT VIBRATION**, like that of the resonators of p. 3. If then we send the powerful white light of an arc lamp into a spectroscope, and then interpose between the arc and the instrument a screen of sodium vapour (in an ordinary Bunsen flame), the yellow light from the arc lamp is absorbed by the vapour.

Thus in the spectrum we see the light from the arc lamp of all wave lengths except that appropriate to sodium vapour; at this point in the yellow the illumination is only that from the gas flame. This latter is far feebler than the rays from the arc, so we have the curious result that two lights give comparative darkness, and the continuous spectrum of the arc is crossed in the yellow by a dull band (almost black by contrast) at the point where the sodium flame, if left to itself, would give its characteristic double yellow line. The dark line is due to ABSORPTION.

DARK LINES IN SOLAR SPECTRUM.—This dark line, with many others, is found crossing the otherwise continuous spectrum of the light from the sun. There is no reason to expect any totally different cause in this case, so we are led to the conclusion that the more brilliantly luminous, because hotter, core of the sun is shining through cooler, less bright strata, which contain sodium vapour. The other lines are found to correspond to other known substances, so the spectrum analysis of the sun becomes an accomplished fact. In some cases the lines cannot be identified with hitherto known elements; hence it was that we knew helium in the sun before we had discovered it upon our earth.

STELLAR SPECTROSCOPY is of similar character, and in the able hands of Sir Norman Lockyer has supplied evidence of an evolution of the elements such as we shall have later to consider from quite another aspect, that of radioactivity. He has shown that the hottest stars have the simplest spectra, that only hydrogen appears to glow in their atmospheres, while the heavier elements successively appear as we point our spectroscopes to cooler and cooler stars. This suggests that the denser elements are actually being formed as the temperature falls by closer states of aggregation of the particles which build the atoms, impossible at the highest star temperatures.

NON-LUMINOUS BODIES.—Absorption spectra are the only ones by which we can study by wave lengths the properties of non-luminous bodies. In the direct case white light is transmitted through the substance, and of course such light as is absorbed leaves dark bands or lines in the resulting spectrum. So light through common blue glass reveals a dark band in the yellow and green, an absorption band. Red and blue light it transmits. Another method is to examine the light reflected by the substance, when again that which is absorbed reveals its absence by a dark gap in the spectrum. Opaque bodies can only be examined in this way. Ordinary metals show little or no selective absorption; that is to say, they reflect all colours indifferently, absorbing a little of each, 5 per cent in the case of silver, far more with such metals as are not so sus-

ceptible of a high polish. Thus the reflected light reveals in the spectro-scope a continuous spectrum only a little dimmer throughout than that of the direct white light. Such coloured metals as copper are obvious exceptions. They are coloured because the light they reflect is coloured; that is to say, is part only of the white light they receive. Copper thus reflects more of red than of other colours, gold more of yellow.

The USES OF SPECTROSCOPY are probably as yet far from exhausted. As a means of chemical analysis the spectroscope far exceeds the test tube in the delicacy with which it can detect minute portions of an element, and carries chemical research beyond the reach of purely laboratory tests to the very heavens themselves. In physics it affords one of the most promising lines of investigation into the composition of the elements. The lines of the spectrum of an element are not strewn pell-mell in the field of view. Simple relations have been traced between the wave lengths for the various lines, so that the spectra of many substances are reduced to orderly series, capable of mathematical statement, by which we may calculate the quickness of vibration for all lines as soon as we know the value for one.

In other fields, such as those of the biological sciences, little has been done, but it is to be expected that systematic spectroscopic study of the colours of flowers, of animal pigments, of the brilliant tints reflected by the wings of insects and the plumage of birds, must lead to important conclusions as to the development of these attractive colorations of the living world. We know, for example, that the colours of birds are due to pigments, to structure, or a combination of the two. The spectroscope is now one of the recognized implements of research in the hands of the botanist, the zoologist, and the physiologist.

ANOMALOUS DISPERSION.—We have said that long waves, such as red, are less refracted than short ones, say blue; but this is only a general rule, and has its exceptions. Fuchsine gives a spectrum in the order yellow, orange, red, violet, the first named being the most bent. There is a dark space between the red and the violet, and the appearance, it will at once be seen, is as though we cut the green out of an ordinary spectrum and then shifted the violet end over beyond the red. Such ANOMALOUS DISPERSION, as it is called, is invariably of this type; some colour is absorbed altogether, and the refraction of the next shorter waves is greatly diminished, so that they run towards or beyond the red end of the spectrum.

ILLUSTRATION OF ANOMALOUS DISPERSION.—The phenomenon is brilliantly shown in the vapour of sodium traversed by white light. A

few small pieces of metallic sodium are put into a horizontal steel tube some 18 in. long, which is then tightly closed by flat glass plates at its ends, and exhausted by an air pump through a tube through one glass plate. Light from an arc lamp is then focused on a horizontal slit through which it passes up the length of the tube. A row of small burners heat the under side of the steel, while wet asbestos tissue keeps the top cool. The result is that the sodium vapour forms as a dense layer below, thinning off to the cool top, and so acting as a prism with its refracting edge uppermost. The light is thus drawn out into a spectrum, and a telescope eyepiece set at the farther end reveals a gorgeous blaze of colour. Instead of the succession—red, orange, yellow, green, blue, violet,—which would be given by a glass prism, we see yellow merging into green and bluish-green, then a dark space, then blue and violet, another dark space, and finally red, grading into yellow again. Now there are two absorption bands in the sodium spectrum; that is to say, two particular wave lengths not transmitted. One is in the greenish-blue and explains the first dark band, the other (double) is in the yellow, and so splits that colour. Here also occurs strong anomalous dispersion, so that the whole blue end of the spectrum, with half the yellow, is shifted bodily beyond the red, being much less bent than it would normally be.

So marked is the effect that exact measurements by Wood have shown that, instead of the usual slowing action of matter upon light waves, in this abnormally dispersed part light actually travels faster than in free space, even up to 300,000 miles per second at its fastest, instead of the 186,000 of vacuum.

CHAPTER VIII

COLOURS—COLOUR PHOTOGRAPHY— DIFFRACTION

The COLOURS OF TRANSPARENT SUBSTANCES such as red glass, solution of blue vitriol, wine, &c., are due to the absorption of all wave lengths except those which produce the colour. Thus ruby glass is red because it absorbs blue, green, and most of the yellow. Cobalt glass is purplish-blue because it only allows blue and red to pass through. This is illustrated by the reflection from the back faces of the glasses. The reflection from the front shows substances in their natural colours, but

in the other everything is tinged with the colour of the glass, because the light has had to pass twice through its thickness. If a substance contains no red, its light cannot be reflected from the back of the ruby glass. Thus a flame coloured brightly green by a thallium salt, and placed so as to show up against the sky in the reflection, appears black.

Ordinary PAINTS show colour for the same reason as transparent bodies, that light penetrates their surfaces and is there irregularly reflected and refracted, and so escapes shorn of the most readily absorbed colours. A yellow paint absorbs blue and violet, and reflects a mixture of yellow, red, and green lights, giving a yellow sensation. A blue paint absorbs red and yellow, and sends blue, green and violet to the eye. The two together therefore absorb everything except green, so that is the colour of the mixed paint. On the other hand, a mixture of blue and yellow *lights*, from the spectrum for instance, give the sensation of white, as is shown if patches of the two colours are thrown upon the same part of a screen from the two nozzles of a "dissolving-view" lantern.

SURFACE COLOUR.—Red ink gives an example of a different state of things. It absorbs green light, and its colour is therefore purplish red. In strong solutions, however, the green is so vigorously absorbed that it begins to be reflected again by the substance, this property, known as surface colour, usually accompanying very intense absorption. Thus the crystals of the substance which have dried on a pen or in a heavy blot appear markedly green. Permanganate of potash and magenta give other instances of surface colour.

INTERFERENCE—NEWTON'S RINGS.—As a wave motion light should be capable of producing interference effects, and this it does in a variety of ways. One of the most interesting is that of NEWTON'S RINGS, the circles of bright colour shown by an air film between two glass surfaces of slightly different curvature, say one flat and the other—lying upon it—a little convex. Reflected light shows a black central spot where the glasses touch, surrounded by a variety of coloured rings. These are produced by the interference between two beams of light reflected respectively from the upper and lower sides of the air film. The second has to traverse a distance greater than the first by twice the thickness of the film, so if this double distance is suitable, the two sets of waves are crest to trough and destroy each other, producing darkness. The distance is the same at equal distances all round the central spot, and the dark region is thus a circular ring. A little nearer the centre, or farther from it, the trains aid each other, crest to crest and trough to trough, and brightness results; thus a series of bright and dark rings alternate.

This is all very well as long as we can speak of "the" wave length, that is, as long as the light is only of one colour, pure blue, or yellow, or red, as the case may be. If, however, we use white light, made up of a great variety of wave lengths, the points of darkness for one will not be so for the others. Hence, except very close to the centre, we do not get black rings, but a continuous series of a sort of rainbow colours, impure because there is frequent overlapping and mixture of tints.

PETROL FILMS—OPALS.—The colours produced by drops of petrol on an asphalted or wet road are produced in the same way. In opals, too, there are successive layers of material, and at each surface of separation interference takes place, giving rise to the shimmering, delicate tints of these beautiful gems. The iridescent shell of many molluscs, such as the ormer (*haliotis*), so much used as electric-light shades in shops, owe their colours to similar films; MOTHER O' PEARL is a familiar example. The colours are often attributed to diffraction, but the above is almost certainly the real explanation.

COLOUR-FILM EXPERIMENTS.—A fine colour film can be prepared in the following way. Dissolve off with alcohol the pink backing of a small piece of mirror glass, and gently polish the exposed silvering with fine rouge on a piece of washleather. Pour upon the surface a solution of collodion in ether; the ether soon evaporates, leaving a film of unequal thickness upon the mirror. Finally silver the film over chemically¹ until the colours appear brightest; at their best these tints display all the colours of the rainbow with wonderful vividness.

LIPPMANN'S COLOUR PHOTOGRAPHY.—The reflection of waves produces, as we have seen, stationary waves, and their formation by light is utilized in Lippmann's natural process of colour photography. The photographic plate, with specially fine-grained emulsion, is placed in a special holder with its film side against clean mercury to form a reflecting wall. It is then placed in the camera, glass side towards the lens, and exposure made as usual. As a simple case, suppose we are photographing a spectrum. Then the red rays falling on the mercury are reflected and set up stationary waves with nodes at the surface of the mirror and every half-wave length from it; here the light is destroyed by interference, but at the points halfway between each pair of nodes, where crest meets crest and trough meets trough, the light exerts its usual photographic action, and,

¹ Thoroughly wash the surface to be silvered and immerse in a mixture of equal parts of the following: (a) Dissolve 1 grm. of silver nitrate in water. Keep back a small quantity, and add ammonia drop by drop to the rest till the precipitate formed is just redissolved; add the small quantity kept aside and dilute to 100 ccm. (b) Dissolve 1 grm. of silver nitrate in 500 ccm. of boiling water; add 0.8 grm. Rochelle salt while still boiling, and filter hot.

on development, black laminations parallel to the surface are produced in the film.

The same is true for each of the other colours, but as their wave lengths get steadily less as we approach the blue end, so the spacing apart of the laminations also decreases. A magnified cross section of the film would appear somewhat as shown (fig. 102).

Now let our developed plate be brought into white light and viewed by reflection from the film side. Light is reflected from each of the darkened layers, but interference annuls the effect of all colours save that for which the distance apart of the layers is half a wave length. The light of this particular colour reflected by the first layer is strengthened by light from the second. For this, travelling half a wave length farther on and the same distance back, is just one wave length behind and so in step, crest to crest, with the first. The third layer, and all below, similarly add their quota to the illumination. Hence where red light fell

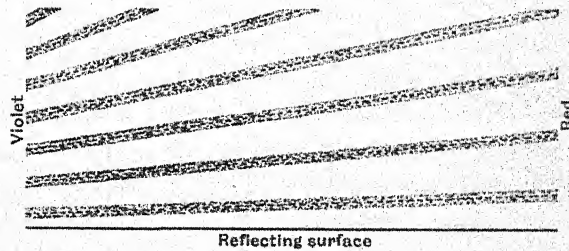


Fig. 102.—Lippmann Film

there red is reflected, while only violet shows where violet was the photographic colour, and so forth. In other words, our plate shows a spectrum like the original. In the more general case similar reasoning shows that a landscape will likewise be produced in its own natural colours.

ORDINARY THREE-COLOUR PROCESS.—This is a real advance, theoretically, on other processes of colour photography, where we use only three colours so chosen as to give by their mixtures the best approximation to the tints of nature. In practice the extreme fineness of grain required in the plates, and the difficulty of manipulation, render good results uncertain, if not impossible, to the amateur.

Three-colour photographic processes are colour-printing devices in which it is ensured that the photographic action of light shall replace the eye of an artist in deciding the final tints, though, of course, the three printing colours have first to be chosen so as to give the best general results.

LUMIÈRE STARCH-GRAIN PROCESS.—This is the most direct and one of the most beautiful and ingenious colour-photography processes. Only one negative is prepared, which is a true colour negative; from it any number of colour transparencies can be made by the usual process of

contact printing. Tiny potato-starch granules of very even size, ranging about $\frac{1}{500000}$ in. in diameter, are stained, some reddish-orange, some green, some blue. The coloured powders are thoroughly mixed, and are then spread closely and evenly over the surface of a glass plate, covered and protected by a varnish layer, upon which is finally laid the photographic emulsion. The plate, thus prepared, is exposed in the ordinary way, except that the glass side is placed to face the lens of the camera. Development and fixing is as usual. Let us examine the resulting negative. Where red has fallen, it has penetrated the red starch grains, and behind them there are produced little blackened spots (after development), thus rendering the red-grain portion of the film opaque. The blue and green particles refused passage to the red light, so the silver salts behind them have not darkened but have dissolved away at fixing. In other words, where red light fell only blue and green light can now penetrate the negative. The grains are far too small to be separately detected by the eye, so the resulting effect is a blue-green uniform colour, the "complementary" tint of red—that is, the tint of light which, added to red, produces the effect of white. So also for patches where blue or green light fell separately. In the case of a mixed colour, say of green and red, the starch grains of both these colours have become opaque (or rather the film behind them has done so), and only blue light passes. Degrees of intensity of the lights are marked by degrees of opacity in the black film. Thus we have a true colour negative, in which the form, colour, and even shades of tint of the original object are recorded everywhere in the complementary colours. To obtain a positive in the true colours, a second exactly similar plate is put behind the negative, printed by exposure to light, developed, and fixed as usual. The opaque granules of the negative corresponding to the colours of nature now protect the positive film from light of their own colour, while the other colours pass through both sets of granules of their own tint, and are blackened out in the positive. Hence red objects in nature are shown as red-transparent parts of the plate, and so forth; we obtain a copy of the object photographed as a glass transparency in natural colours.

DIFFRACTION.—An early objection to the wave theory of light was based on the fact that its rays seem to travel rigidly in straight lines, unlike sound and other wave motions, which show diffraction. The bending around corners in sound, however, is rendered so obvious because the length of the waves concerned is comparable to the sizes of the obstacles they meet. Very large bodies *do* throw sound shadows, and, conversely, very small ones show the bending or DIFFRACTION of light waves around

them. Thus Poisson, working out mathematically the consequences of the wave theory, discovered that a point of light should appear in the middle of the shadow of a small circular object, a result which appeared so ridiculous that it was held to refute the theory. And yet nothing is easier than to show this bright spot. The experiment succeeds quite easily in an ordinary long room into one window of which the sun shines. Place a mirror obliquely at this window, so that a beam of sunlight is projected across the room. Make a large clean pinhole in a piece of tin, and set it in the way of the sunbeam so that only a narrow pencil gets through. Put a small telescope (one limb of an opera glass will serve) at the far end of the room in this beam, and focus it on the pinhole. Now fix a farthing or a threepenny piece by wax to a fine wire or two threads, and support it between the pinhole and the telescope so that its shadow falls in the field of view. The farthing, of course, is not sharply in focus; but at the centre of its dark disc appears some amount of light, and by adjusting the distance of the coin this can be reduced to a brilliant spot. Light does not of course really penetrate the coin, but bends round its edges. To see that this is so one only needs to re-focus the telescope on the coin itself; it appears surrounded by a bright halo of light, though the pinhole is quite hidden.

Diffraction is shown, too, by various small obstacles or narrow openings. If a needle is examined in the same way as the coin, coloured fringes will be seen to run parallel to it, spreading out somewhat at the tip. A small round aperture or a narrow slit presents each its own interesting figure, and it will soon be observed that each shape of obstacle or aperture has a quite characteristic "diffraction pattern". Other diffraction effects are the coloured stripes seen when one looks at a distant arc light through the narrow slit formed by placing the first and second fingers as close together as possible.

These patterns may be visible when the objects producing them are too small to be seen even by the highest powers of the microscope. Light is sent obliquely through milky or "opalescent" liquid, for example, so as not to pass up into the microscope tube direct. The field, however, at once lights up with little diffraction circles of light, showing the existence in the liquid of tiny particles which are the cause of the milkiness.

DIFFRACTION GRATING.—The diffraction patterns of a number of fine slits placed closely side by side produce regular and well-defined spectra, the red most deviated and the violet least (contrary to the order in prism spectra). Such an arrangement is the **DIFFRACTION GRATING**, most used of all instruments for the production and examination of spectra. It

consists of a plate of glass or metal upon which are ruled evenly a host of parallel scratches, causing breaks in the regular reflection or refraction of light falling upon the plate.

It may be ruled on speculum metal by a dividing engine armed with a fine diamond point, a common ruling in good gratings being that of 14,000 lines to the inch. The spectra are then seen by reflection.

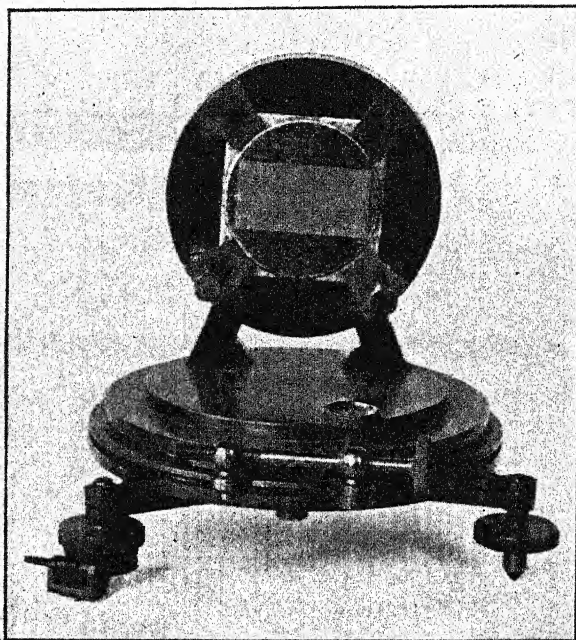


Fig. 103.—Rowland's Diffraction Grating

A simple grating may be made with quite a few lines to the inch by ruling smoked glass. Smoke the glass as evenly as possible by burning a little turpentine on a wisp of cotton wool. Next run a very little methylated spirits quickly over the smoke film and allow it to dry; the film will now be found to be dense enough to scratch cleanly with a sharp point. It may be ruled by the aid of a scale and T-square, with the point of a needle, at distances as small as can be set off evenly. A rough-and-ready method which gives a fair show of colour is to rule the surface all at once with the points of a fine tooth comb. Reflections of a flame or, better, of a narrow beam of sunlight, appear drawn out by such gratings into beautiful rainbow fringes.

CHAPTER IX

POLARIZATION—OPTICAL RESONANCE—
FLUORESCENCE—PHOSPHORESCENCE—
CINEMATOGRAPH

PLANE POLARIZED LIGHT.—If two unsilvered mirrors of plate glass are backed by black varnish and set parallel to each other, the line joining their centres making an angle of about 33 degrees with either, then light falling on the first so as to be reflected to the second is again reflected by this. A simple way of setting up the apparatus is to saw an oblong wooden block into two halves by a cut making 33 degrees with its faces. Glue the two mirrors upon the oblique faces, and, setting up the blocks A and B, as shown (fig. 104, upper diagram), look at the flame of a candle C, as reflected by both mirrors; if we now gradually turn the block B over, the reflection fades until in the position of the lower figure the flame is no longer visible. The light reflected from the first mirror has thus a sort of two-sidedness, and is said to be **PLANE POLARIZED**. Its "plane of polarization" is defined as that in which it is most copiously reflected, and is thus the plane in which the ordinary unpolarized light falls upon and is reflected from the first mirror.

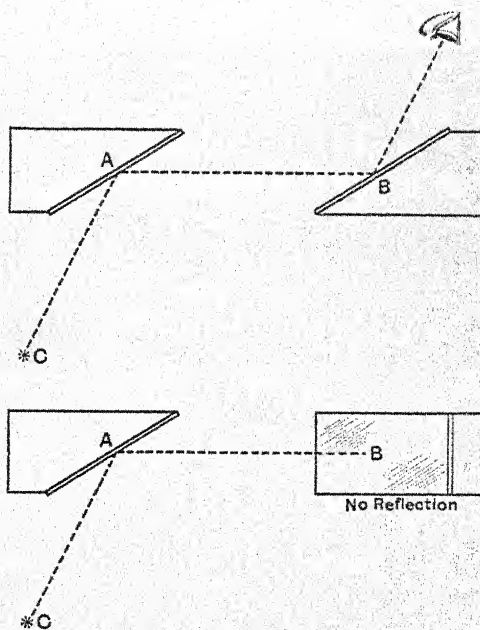


Fig. 104. —Polarization by Reflection

Plane-polarized light, it may be at once stated, is light in which the vibrations in the ether are all in the same plane. This plane is perpendicular to the so-called plane of polarization as just defined, so that in our experiment the ether vibrations of the polarized beam were parallel to the surface of A.

OTHER POLARIZATIONS besides plane may exist; if the vibrations are in circles we have circularly polarized light, if they are in ellipses the

polarization is elliptic. These forms we cannot deal with in this brief summary.

MODEL OF POLARIZATION.—The phenomena of polarization may be modelled by a stretched string, representing the path of a beam of light. Let one end be attached to a rigid support, the other held in the hand. If then the hand is moved sharply up and down, to and fro, in straight lines, circles, ellipses, in any way whatever, so long as the string is kept taut, waves are sent along it with a speed which depends only on the stretching pull, not at all on the kind of shake that is being practised. So light travels at the same speed whatever may be the form of vibrations

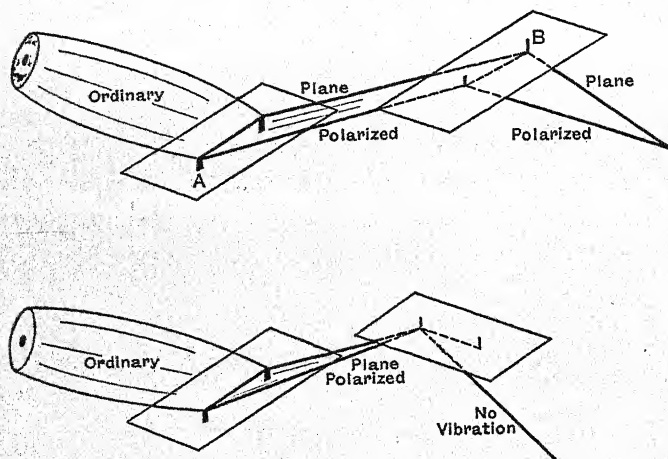


Fig. 105.—Polarization Model

in its waves. Now let the hand be shaken to and fro in straight lines, first horizontally, then vertically, then obliquely, with many consecutive shakes in each direction. Then an observer would see the waves passing along the string in various planes according to the motion of the hand; but if this motion could be made rapid enough, and the changes followed each other at sufficiently short intervals, he would only see by the blurred appearance of the string that it was indeed vibrating. By altering his position and point of view he could also satisfy himself that it vibrated in all directions alike, but he could not detect the transitions from one mode of plane vibration to another. The string is now a model of a beam of ordinary light, in which plane vibrations, and probably mixed circular and elliptic vibrations, follow each other with great rapidity. The waves of ordinary light arrive at the rate of about 600 billion per second, so that even if the vibrations of any one particular kind were as many as 600,000,000, yet the changes from one type to another would take place 1,000,000 times

a second; of course the result must be that in ordinary light the vibrations appear in all directions at once, so to speak, showing no signs of the two-sidedness we call polarization.

But if the string is vibrated to and fro always in the same way, then the waves along it are polarized, plane, circularly, or elliptically, according to the kind of motion of the hand. The "plane of polarization" in the first case is that parallel to the string at right angles to the direction of its motion.

The production of plane polarization by our glass mirror can be modelled by looping the string under a wire parallel and close to the mirror. Then, however the hand at one end of the string may be moved about, the wire prevents the transmission of all waves having their vibration perpendicular to the mirror, and consequently on the further side the string only vibrates in one direction, that parallel to the plane of the mirror.

Translating into the language of light, the reflected beam is plane polarized. If now the string is slipped under a second similar wire attached to the second mirror, this puts no further check on the vibrations so long as they are parallel to the

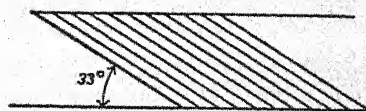


Fig. 106.—Cover-slip Polariscope

wire. In other words, if the two mirrors are in the parallel position, as above described, the plane-polarized waves of the string (or light) pass on, again reflected. But if the constraining wires are not parallel, the second acts as a partial check to the vibrations passed by the first, and, if they are exactly at right angles, stops them altogether; in other words, the second mirror completely refuses to reflect the light sent by the first.

POLARIZATION OF REFRACTED LIGHT.—Plane-polarized light is also produced in some cases of refraction. For instance, tourmaline only allows vibrations in one direction in the ether within its substance, so light passed through a tourmaline plate is plane polarized. The model would be a card with a slit in it, through which the vibrating string passed; whatever vibrations might arrive along the string, only those parallel to the slit could be transmitted.

COVER-SLIP POLARISCOPE.—Glass plates set at the above-mentioned polarizing angle of 33 degrees with the beam of light, show polarization in the refracted as well as in the reflected light, the planes of polarization of the two being perpendicular. The transmitted light is only very slightly polarized with a single glass plate, but a very handy polarizer can be made by placing about a dozen thin-glass large microscope cover slips together, like a pack of cards on edge, then letting them slide over each other (still

in close contact) till their faces make about 33 degrees with the table, and fastening them together by lightly gummed strips of thick black paper across the edges at each side of the opaque-angled block of glass thus formed. The whole may be mounted inside a sort of square cardboard tube made by a long strip of the paper, a little wider than the length of the block, wrapped round the edge, turn after turn, the inner side being first gummed and each corner bent sharply and neatly. Two such sets of strips should be prepared, one for polarizing ordinary light, the other to examine or "analyse" the polarized beam.

If the two tubes are now set in line with their corresponding directions, at right angles, it will be found that no light can pass through, while if one be turned, light passes more and more freely until the rotation is a right angle either way, when the transmitted beam is at its brightest.

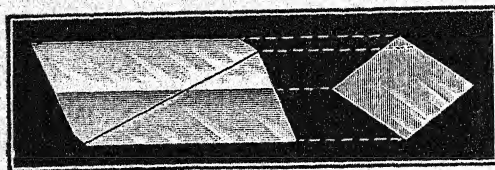


Fig. 107.—Nicol's Prism

DOUBLY REFRACTING CRYSTALS.—Some crystals have the power of double refraction, that is to say, a ray of light is split into two in passing through them, the bending being different for the two refracted rays; the

two are always polarized at right angles to each other. Thus put a black dot of ink upon a sheet of paper, and lay a crystal of Iceland spar upon it; two dots appear, and if these are examined by one of our piles of glass plates, one becomes invisible at a certain position of the plates, and the other when the pile is turned through a right angle.

NICOL'S PRISM.—An instrument more often used than the pile of glass plates to produce a beam of polarized light is the NICOL'S PRISM. It does not waste so much light by reflection as the plates do, and so gives a stronger beam, but it is much more expensive. It consists of a crystal of Iceland spar cut through diagonally as shown, and joined together again by a thin cementing film of Canada balsam. The spar prism, as we have already seen, breaks a ray of light into two rays, which take different paths, being unequally refracted, and each of the two is plane polarized. The use of the balsam is to stop one of the two; this it does by totally reflecting (p. 10) the more readily refrangible ray, which is thus diverted to the side of the tube containing the crystal; this is blackened and absorbs the ray. The other, the less refracted, passes through the film and the second half of the crystal, and so emerges as a beam of completely plane-polarized light.

CRYSTALS AND POLARIZED LIGHT.—Crystals have in general a remarkable effect upon beams of polarized light, showing beautiful bands and brushes of curious shapes and brilliant colours.

Pass light through one pile of plates, and then converge it by a moderately powerful magnifying glass upon a thin strip of mica (a piece split from an old gas shade will do perfectly). Examine the light through the second pile of plates. The mica appears tinted with the most beautiful colours, which change with its position and thickness and with the angle of the analysing pile of plates. Iceland spar, saltpetre crystals, and quartz show other more complicated systems of coloured rings and spirals and light or dark crosses.

Ordinary GLASS in a state of *strain* shows such brushes. Heat a piece of clear glass red-hot and throw it into water, choosing a few of the largest fragments for the experiment. In this case the glass has its optical properties different in different directions, and so resembles a crystal in its treatment of polarized light.

A beautiful effect is obtained by melting a little BENZOIC ACID on a hot glass plate and examining it in this way with the aid of a magnifying glass, as it crystallizes out on cooling; the growth of the crystals, pretty in itself, is rendered yet more exquisite by the varied polarization colours which shoot out over the plate as the process goes on.

THE POLARISCOPE IN GEOLOGY.—Thin sections of most minerals and rocks are transparent, and their examination by the transmission of polarized light has proved a most important method of research during recent years. It forms part of a method of optical analysis which not only enables rocks to be identified with certainty, but also helps us to understand their mode of origin and the changes which they have since undergone.

THE POLARISCOPE IN ECONOMIC BOTANY.—The discovery of new kinds of VEGETABLE FIBRE is a matter of no small importance. Such fibres, examined in plant sections by means of polarized light, exhibit characteristic colours which renders them conspicuous. This greatly helps in forming a sound judgment as to the quantity of such fibres present in a given case. The polariscope is also of use to the analytical chemist in work on food or drugs.

ROTATORY POLARIZATION.—Certain substances possess the property of gradually changing the plane of polarization of a polarized beam passed through them, *i.e.* rotating it, whence the name of ROTATORY POLARIZATION. QUARTZ shows the property in the highest degree, turning the plane through about 55 degrees for each tenth of an inch thickness. Sugar solutions also rotate a polarized beam, a fact that is

made use of in "Saccharimetry", or the determination, for commercial or fiscal purposes, of the amount of sugar in liquids of various kinds.

ACTION OF SMALL PARTICLES ON LIGHT.—When light falls on a cloud of small particles, such as the motes in a sunbeam, it is scattered in all directions, and the light may illuminate a whole room. A charming experiment is made by passing a narrow ray of sunlight down a glass tube placed with one end against a hole in a shutter by which the light enters, and the other projecting into a box with the point of entrance well packed round with black paper or velvet. As long as the tube is filled with a clear liquid it is barely visible; the light passes straight through, and is lost inside the box. If now the liquid becomes cloudy, the appearance changes; a quite weak clear solution of ordinary photographic "hypo" may be used, and then rendered cloudy by a few drops of dilute sulphuric acid. For a minute or two the liquid remains clear, but then a very fine precipitate of sulphur appears and scatters the light. The colour is at first a beautiful blue, because the shortest wave lengths are first affected, the longer ones only as larger particles are formed, when the scattered light becomes white. The blue smoke from the tip of a cigarette, and its browner hue from the mouth, are other illustrations of the effect of the increased size of the particles in the latter case.

COLOUR OF THE SKY.—The blue colour of the sky is due to the irregular scattering of light by dust particles, or by the molecules of air themselves. On the other hand, the sun is red at sunset because the blue and green rays are scattered, and only the redder rays pass straight from him to our eyes. His red colour when viewed through smoked glass is due to the same cause; the cloudy hypo solution also appears reddish by transmitted light.

SCATTERED LIGHT IS POLARIZED.—The light scattered by small particles is plane polarized, as can be shown by examining the cloudy hypo tube by one of our piles of plates. Another method is to send polarized sunlight along the tube, when the luminescence is seen only to occur on two opposite sides of the tube.

SUGAR-SOLUTION EXPERIMENT.—This leads up to another beautiful experiment; if the liquid is a strong solution of sugar, made opalescent as before, the rotation of a plane of polarized sunlight is rendered visible by the particles as a spiral of scattered light. As the various coloured rays making up the sunlight are differently rotated, this spiral is beautifully tinted, and turning the pile of plates producing the polarized beam causes the spiral to describe a sort of screw motion in the luminous tube.

OPTICAL RESONANCE.—Particles much smaller than even those of

dust in air or sulphur in hypo may have their natural periods of vibration the same as those of light. Light waves, as we shall see, are electric waves of minute length. Now a metal sphere, charged with electricity, has a natural frequency of vibration, in which that electricity if disturbed will surge to and fro; the fact is made use of in wireless telegraphy. Electric waves of the right frequency can set up these surgings by resonance. Make the sphere smaller, and you require to make the waves shorter and quicker to match; if the sphere becomes a very minute particle, its natural frequency may agree with that of light waves. Then light falling on such particles will set them vibrating as a whole, just as sound waves falling on a tuning fork set it vibrating if the frequencies agree. Such a case, then, is OPTICAL RESONANCE; the minute particles will send out light of their own particular wave length like the tuning fork, "resounding", or rather, if one may say so, "relighting" to the waves they absorb.

Professor Wood shows this effect by enclosing a few little pieces of sodium or potassium in a small glass bulb, which is then exhausted by a good air pump, and finally sealed up. On heating the metal by a small flame, so that it distils in tiny particles on to the cool parts of the bulb, brilliant purple or blue films appear, accompanied by scattered red or green light. The condensed particles of metal are so minute that they are capable of quivering in response to the shake of the waves of the light which falls on the bulb.

FLUORESCENCE.—Besides ordinary absorption, certain substances have the power of transforming light of one wave length into waves of quite different length; *e.g.* the cool light waves focused by Tyndall upon a piece of platinum after the absorption of all heat waves soon raised it to red heat. In other cases it is not heat but light which is produced, of another colour than that of the light received. This is FLUORESCENCE, and is well shown by a solution of quinine sulphate which shines blue when exposed to strong white light, as does also ordinary paraffin oil.

The green solution in alcohol of the chlorophyll of the leaves of plants fluoresces red in ordinary light, while many substances light up green, red, or blue under the stimulation of moderate heat or of cathode or X-rays. There appears to be a distinct possibility that at any rate some cases of fluorescence may prove to be due to an effect of resonant vibration of the electrons under the stimulation of ether waves, akin to ordinary optical resonance. The greenish-yellow uranium glass, quite commonly used for vases, fluoresces a most vivid and beautiful green when held in sunlight.

When the phenomena last after the exciting light is cut off, as, for instance, with Balmain's luminous paint, we have PHOSPHORESCENCE;

but the difference is merely one of degree; all fluorescent bodies do phosphoresce, though usually for an exceedingly short time.

THE CINEMATOGRAPH.—This apparatus makes use of the fact that a picture formed upon the retina of the eye affects the sense of sight for about one-tenth of a second. Thus, if a number of successive photographs are taken of any moving object, and these views, made into lantern slides, are projected rapidly one after another upon the same spot on a screen, the eye cannot detect the dark intervals between the successive pictures, but gains a general impression of the series of scenes in order; in other words, the moving object appears to actually move upon the screen, not to be depicted several times in different attitudes. There is usually a certain amount of flicker, which is due to the discontinuous changes which are really going on. In the cinematograph the successive photographs are taken upon a long roll of film, which is passed by clockwork mechanism uniformly in front of the projecting lantern. The time of illumination of each view must not, of course, last long enough to reveal its motion as a whole across the screen, so a rapidly revolving sector, a sort of fan, is arranged to shut off the light, except for a very brief instant when each scene is centrally upon the screen. Thus the impression obtained is that the objects of the view are moving within the limits of the picture as they moved in reality, while the picture as a whole, the background, and all stationary objects keeps a fixed position upon the screen.

The scientific employment of the cinematograph is in its infancy, but already valuable records have been obtained of savage dances and rituals and of many historic events. In the study of the flight of birds it will without doubt yield results of the first importance to research upon aerial locomotion; in physical science it records for us the exact stages in the motion of such bodies as falling or splashing water streams, and the vapour and smoke bursts of explosions; in surgery it can be employed to photograph every stage in rare major operations. The great value of the instrument in these matters lies in the fact that the subsequent repetitions of the scene may be conducted at any speed, the exact instant of a splash can be lengthened out by slow running of the film, the critical instant of the operation repeated with a leisureliness impossible in the operation itself, but necessary to a proper understanding by the medical student; above all, perhaps, the scene can be repeated as often as required, and the attention directed upon each feature in turn.

BOTANICAL APPLICATIONS OF THE CINEMATOGRAPH.—Mrs. Scott has recently devised a most interesting application of the cinematograph to the movements of living plants. It is a familiar fact that plants of the

kind (*e.g.* Hop and Convolvulus) gradually climb up a support by turning round so as to describe either a left-handed or right-handed spiral. Such movements are so slow as to be inconspicuous, but Mrs. Scott has taken successive photographs in a cinematograph film at relatively long intervals of time. By passing such a film rapidly through the apparatus the plant appears to climb rapidly up the supports after the fashion of a snake.

CHAPTER X

OPTICS OF THE EYE—INFRA-RED AND ULTRA-VIOLET RAYS—RADIATION PRESSURE

STRUCTURE OF THE EYE.—The eye is a sort of camera, and is subject to many defects. It is nearly achromatic, however, and distorts but slightly. The **RETINA**, a sensitive concave disc to which the endings of the nerves are attached, corresponds to the sensitive photographic plate, except that light instead of producing a permanent negative by chemical change acts by a nerve stimulus, by chemical or some other action, and so produces a transient impression in the perceptive portion of the brain, what we describe as a **SENSATION OF LIGHT**. A pigment in the retina known as the **VISUAL PURPLE** appears really to chemically resemble a sensitized plate, for upon it light has a definite chemical action resulting in bleaching to yellow or white; however this purple does not seem to occur in the most sensitive central part of the retina, so its function is quite uncertain.

RODS AND CONES.—The sensory portions of the retina are of two kinds, the rods and the cones. Their exact function is unknown, but at any rate the cones seem to play an important and specialized part in colour vision. It is known that whatever the colour of a body it appears grey if placed in sufficiently dim light. Lummer explains this by the supposition that the rods are very sensitive to light in general, and so give this grey effect, but the cones, though less sensitive, are necessary in the perception of colour.

FOCUSING OF THE EYE.—The focusing of the eye camera is effected partly by the motion of the lens bodily, but chiefly by alteration of its curvature under the pull of muscles attached to it and to the firm covering of the eyeball. A normal eye can thus be focused upon any object at a distance of more than about 10 in., the usual "least distance of distinct vision". To view objects closer than this a weak magnifying glass can be used.

INVERSION OF THE IMAGE.—A convex lens such as that of the eye forms **INVERTED IMAGES**, though the mental picture we form through them has of course no such peculiarity. That the inversion really occurs can be shown by throwing a *shadow* on the retina. Make a good-sized pinhole in a piece of card and hold it 1 in. or less from the eye. Look

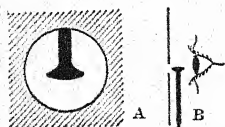


Fig. 108.—Inversion of the Image upon the Retina

through it at a white ceiling or at the sky, and then bring a pinhead slowly up into the line of view as shown in fig. 108 B, between the card and the eye. The pin is too close to be seen directly with the eye focused on the distant ceiling, but its shadow is thrown on the retina, and, though of course really erect, appears upside down, as in fig. 108 A.

SHORT SIGHT OR MYOPIA.—Short sight or myopia results from too great curvature or too high refracting power of the lens, so that objects can be seen distinctly from a least distance less than the normal 10 in., but with a further limit also to clear vision. For instance, a short-sighted

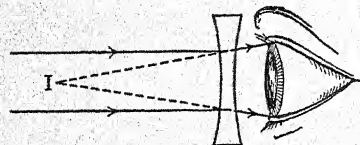


Fig. 109.—Short Sight

person may only be able to focus objects sharply if they are farther than 6 in. and nearer than 2 ft. To correct the excessive refraction a concave spectacle lens is used, and should be so chosen that light from a distant object appears to come

from the farthest limit of clear vision—in the case taken, from 24 in. away; this must therefore be the focal length of the concave lens. In some cases such a lens, to give clear distant vision, brings the image of nearer objects inside the minimum range of focusing, so that a second weaker pair of spectacles has to be used for reading.

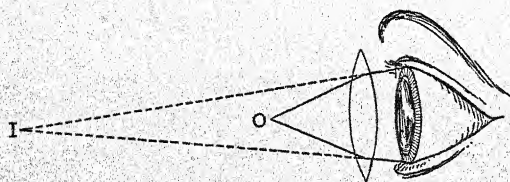


Fig. 110.—Long Sight

LONG SIGHT OR HYPERMETROPIA.—Long sight or hypermetropia (**PRESBYOPIA** in middle-aged or old persons) is the reverse defect; no object can be focused unless it is at some distance

from the eye—say 3 ft.—considerably beyond the usual 10 in. Convex glasses correct this defect, giving a compound lens of shorter focal length, and so supplying the necessary increased refraction for short distances. For instance, a lens of 18 in. focal length will apparently shift an object O from 1 ft. away to 1 at the distance of 3 ft. required, as shown.

ASTIGMATISM.—Astigmatism, just as in glass lenses, is due to unequal

refractive power in different directions, and is here chiefly caused by irregularities of the cornea, the bulging front portion of the eye. It is an exceedingly common defect, and is allowed for by lenses which are partly cylindrical, that is to say, the faces are not truly spherical but curved more in one direction than in that at right angles. The greatest curve is in the plane of greatest curvature of the eye, and vice versa, so that the excessive convexity of the eye in one direction is met by excessive concavity of the spectacle lens. Spectacles to correct astigmatized sight can at once be detected by the form of the reflection they cast in sunlight. At one particular distance, varying of course with the strength of the lens, this reflection is a straight line parallel to the direction of least curvature of the surface. At other distances the line broadens out, and the reflection is more or less oval in outline.

THEORY OF VISION.—The actual theory of vision is not so simple as the above mechanism might suggest. It appears to be necessary that the whole diffraction pattern produced by any object should fall on the retina in order that the mental picture we form shall be accurate; and that the patterns of two neighbouring objects should lie clear of each other is the condition that one may be seen as separate and distinct from the second.

An experiment shows this in the most striking way; pass sunlight through a pinhole in a sheet of cardboard, and focus it sharply on a second white card by means of a lens. Just in front of the screen put a small piece of very fine-meshed wire gauze with its two sets of wires respectively horizontal and vertical. The bright squares on the screen appear bounded by diffraction patterns, consisting of four sets of spectra, two parallel to the two lines of wire in the gauze and the others bisecting the right angles between the first two. Make a very small hole in the screen, so that only the bright part of one of the squares is cut out, and cautiously look through the hole from behind, along the beam which passes through. The gauze is invisible. Next cut a narrow slit in the card, and set it so that a bright square and the horizontal line of spectra pass through; the vertical wires now appear, but there is no trace of the horizontal ones. Turn the card through a right angle, and these latter appear, but the vertical wires vanish. Strangest of all, set the slit obliquely so that the oblique spectra pass through, then diagonal wires at right angles to the slit at once come into view—it is hardly possible to believe that they do not exist. Two slits in cross form X give the appearance of a complete phantom gauze resembling the real one turned through 45 degrees angle.

THE EYE AND POLARIZED LIGHT.—The eye can detect polarized

light to some slight extent, by reason of the double refraction of the "yellow spot", a central depressed area of the retina. If we view a bright cloud through a polarizer, such as the pile of glass plates, which is at the same time steadily turned so that the plane of polarization slowly changes, we after a little search see a sort of yellowish tufted band with a blue patch on each side of it, figures like the brushes and rings of crystals, but produced in the eye.

Again, if we glance quickly at a bright cloud through a solution of chrome alum in a flat white glass medicine bottle the ordinary purple colour of the solution seems to contain a central redder spot. The solution transmits both red and blue rays, and the latter are absorbed by the pigment of the yellow spot, so that the portion of the cloud whose image falls on the spot is seen by red light alone. One interesting conclusion to be drawn from this is that the chain of events leading to the sensation of light begins at the *back* of the retina, for otherwise the absorption by the yellow pigment would be too late to affect our sight.

In the field of COLOUR VISION the eye presents most interesting features. As stated above, the sensation of colour requires light of a certain definite strength to stimulate it. If a red light is gradually turned down, the sensation of redness weakens, until at last there is merely the impression of light, none of colour. Careful work on this subject shows that the colour vanishing point is reached, for different tints, at different brightnesses. This suggests that the colour mechanisms of the eye are distinct from each other and from the mechanism of light perception in general; perhaps, as suggested, the cones and the rods have here their respective uses. Three such colour-perceiving devices appear to explain the facts, and the Young-Helmholtz theory of colour vision supposes that these react respectively to red, green, and violet. Mixtures of light of these colours can be made to match any tint whatever. White can be built up of all three in suitable proportions, colours usually by two alone, when a suitable admixture of white will change it from its pure tint to any required degree of lightness.

COLOUR BLINDNESS.—Colour blindness results from an absence of one or very rarely two of the sets of perceptive apparatus. The defect is frequently congenital, though in a different form it is sometimes produced by excessive smoking of strong tobacco.

The most usual type is GREEN BLINDNESS, *i.e.* lack of perception of green; nearly 4 per cent of men are partially or entirely green blind, though women suffer thus to a much smaller extent. Red blindness and violet blindness are also known, though the last is quite rare, a fact which

suggests to Sir William Abney that violet was the colour sensation earliest experienced by the ancestors of mankind, red and green following in order at later dates.

TESTS FOR COLOUR BLINDNESS.—As an illustration of the sort of mistakes a colour-blind person is likely to make, Abney gives the experiment of superposing on a screen light from three parts of a spectrum—red, bluish-green, and violet. With these three a white is produced, which to a colour-blind person also appears white. Now shut off the red light, and we have a bright greenish-blue patch of light; but the patient still calls the patch white. Similarly, the red and violet alone produce a strong purple, which a green-blind person sees as white, while a violet-defective vision could not distinguish between real white and the yellow mixture of red and green lights.

A doubly colour-blind subject, perceiving only one colour, has practically the sort of vision represented by an ordinary photographic camera, monochromatic, merely distinguishing shades of brightness and darkness in the one tint remaining.

A red-blind person matches bright red with quite dark grey; if a white patch and the red one are placed side by side, the former has to be darkened down to an extraordinary extent before he declares them of equal brightness.

The normal eye has no power of dissecting a colour into its constituent primary colours; for instance, the yellow light transmitted by a solution of potassium chromate and blue litmus really contains no yellow at all, but merely red and green, which, mixed together, convey a yellow impression to the eye.

IMPORTANCE OF TESTS FOR COLOUR BLINDNESS.—The use of coloured flags and lamps in railway, military, and naval signalling lends peculiar importance to the tests which have been devised for the detection of colour blindness. The danger of putting a red-blind man in charge of a train is very obvious, and the Board of Trade examines candidates for railroad and merchant-service appointments to ascertain the normality of their colour perceptions. The usual tests are to place before the examinee a number of skeins of wool (Holmgren's colour skeins) of many well-considered shades; these he is asked to sort out into reds, greens, &c., and afterwards to match certain shades. Even partial colour blindness always stumbles somewhere in these tests, but there is one form of colour blindness brought about by disease which may pass the examination. In this type of the defect it is only the extreme central part of the retina which is affected, so anything as large as a skein of wool may be correctly appre-

ciated by the candidate "out of the corner of his eye". A further test by small beads at once removes any doubt, for here the attention has to be fixed precisely on the bead in order to pick it out, and even when a candidate catches sight of the desired colour it changes and eludes him as he glances toward it.

Malingers occasionally appear, shamming colour blindness as a ready means of escape from a service of which they have wearied; the wool tests never fail to betray their trickery. True, they invariably pick up the wrong colour, but the examiner knows precisely what shades a true colour-blind subject will confuse, whereas the malingerer does not. Hence when a self-styled red-blind man chooses pale-blue as a match for red he proclaims his fraud; a veritable subject would have picked out a very dark almost black skein.

INFRA-RED RADIATIONS.—Light, as we have seen, consists of waves of many lengths; these for the ordinary eye lie between about $\frac{7}{10000}$ mm. for the extreme red, and about $\frac{4}{10000}$ for the furthest violet. But an ordinary source of white light really emits waves going far beyond these limits in both directions. If we form a spectrum of the light, say by a reflection grating, a delicate thermometer such as the radio-micrometer shows that the heating which is observable in the coloured region extends to the red end, and beyond it into darkness, even up to a position representing a wave length of about $\frac{1}{1000}$ mm. These are the **INFRA-RED RADIATIONS**.

ULTRA-VIOLET WAVES.—Similarly a photographic plate will reveal that beyond the violet end stretches out another long train of waves running up to wave lengths as small as $\frac{1}{5000}$ mm., the **ULTRA-VIOLET WAVES**.

LONGEST AND SHORTEST WAVES.—Recently our knowledge of these two trains, infra-red and ultra-violet, has been greatly extended by the detection of far longer heat waves, up to $\frac{3}{80}$ mm. by Rubens and Nichols, and of far shorter ultra-violet waves, $\frac{1}{10000}$ mm. long, by Schumann and Lyman.

The long waves were found by making use of the fact that light of a wave length which is powerfully absorbed by a substance is often powerfully reflected by it also as a surface colour (p. 19). Fluorite shows this effect for long waves, so a beam of light from an ordinary incandescent Auer gas mantle was passed to and fro between two fluorite surfaces, gradually losing by the successive reflections all the other waves which were not much reflected, until a practically pure beam of the wave length sought was left, the so-called "residual rays".

It will be seen that these waves are 100 times as long as those of ordinary light, so they are a halfway mark between light and the shortest electromagnetic waves of the laboratory, which are 100 times longer again.

SHORTEST WAVES.—The shortest ultra-violet waves measured by Schumann are somewhat readily absorbed by air, and had long remained undiscovered. Schumann has photographed them in vacuo in the light of hydrogen vacuum tubes, on plates in which the highly absorbing gelatine emulsion was avoided by depositing silver salts upon the glass itself. Lyman recently gives reasons for thinking that the extreme absorption attributed to such rays in air has been exaggerated.

RADIATION PRESSURE.—Upon any wave theory of light the incidence of waves upon any surface means the impact of a certain amount of energy; thus, for instance, heat is frequently produced by light waves. There should therefore be a mechanical pressure exerted by light on a surface upon which it falls; this **RADIATION PRESSURE** was foreseen by Maxwell long before it was actually detected. It is extremely small, and its effects are readily obscured by the radiometer action of the heated gas molecules about the surface. However, in 1900, Lebedew, and a few months later Nichols and Hull, observed the pressure. Nichols and Hull's method uses a radiometer with two vanes, not free to spin about freely, but suspended by a Boys' quartz fibre, so that the pressure merely deflects it through a definite angle. The gas difficulty is avoided in the simplest case by having one face of each vane plain glass and the other face silvered. The radiations are first passed through glass plates so that any waves capable of heating glass have already been absorbed when the light reaches the radiometer. Suppose the light falls on the glass face, then it passes through, and any heating occurs at the silver surface. Consequently that surface experiences a pressure, due to the radiation, in the direction of the light, and a pressure in the opposite direction due to the ordinary Crookes's radiometer effect. The latter is the greater, so the vane is deflected towards the light to an amount depending on the difference between the two. Next allow the light to fall immediately on the silvered side; the two pressures now aid one another, and the deflection, in the direction of the light, is greater than before. The difference of the two deflections measures twice the radiation pressure. This pressure is extremely small; with Nichols and Hull's apparatus, using an arc lamp, it was between two and three thousand-millionths of an ounce weight.

These results, and those of later experiments (1905) by Hull, are in exceedingly close agreement with the calculated values of the pressures

for the sources of light employed. Small as these forces are, it can be shown that they can overcome the force of a body's weight, if only the body is small enough. The reason is simple: the radiation pressure depends on the extent of surface of a body, its weight upon its volume. So every time we halve the length dimensions of a body we, it is true, reduce its surface, and therefore the radiation pressure on it, to one-quarter; but at the same time its volume becomes eight times smaller, and its weight of course decreases in the same proportion. If the halving process is repeated many times, we can reduce the weight so much more than the pressure that the two become equal, and for smaller bodies still the weight is the less important of the two.

COMETS' TAILS.—Now, in the tail of a comet there is matter in a state of extremely fine division, and in the neighbourhood (*i.e.* at a distance of a few million miles) of such a fiercely radiating body as the sun the light pressure on these tiny particles may well exceed their weight under the sun's attraction. Consequently the tail of such a comet should point away from the sun, which is exactly what it does when the comet is at its nearest. Sometimes an attracted tail is seen, sometimes both varieties, suggesting that the sun has sifted the particles and is attracting the heavier by its gravitation, while repelling the lighter by its radiation.

Light spores or seeds may similarly be driven through space by the repulsive forces of the sun's light, and so may possibly transfer plant or even animal life from one planet to another in their emigration.

CHAPTER XI

ELECTRICITY—MAGNETIC FORCE AND ELECTRIC CURRENTS—ELECTROMAGNETS—TELEGRAPHS —TELEPHONES

Before we consider the modern views of the nature of electricity let us recall a few of the bald facts of magnetism and the electric current.

POLES OF MAGNETS.—A magnet attracts iron and steel, but not by all parts of its surface. The two attractive regions, one at each end, are called its POLES. These are not exact copies of each other, for a suspended magnet, such as an ordinary compass needle, always points north and south with the same end, thence called the north pole of the magnet, towards the north. Another magnet affects the compass, a south pole

attracting a north and vice versa, while two north poles or two south poles repel each other, *i.e.* tend to drive one another farther apart.

ELECTRIC CURRENTS.—If we join the ends of a copper wire to the two poles of a "galvanic" cell, such as the Leclanché which rings our electric bells, then the wire becomes warm, showing that something is going on in it which involves the production of energy, manifested by this heat. A compass needle brought near is affected; if the wire is held in the north-and-south line just above it, the needle turns on its pivot so as to rest at an angle with its old position. The copper is not in itself a magnet; the magnetic forces, like the heat, come into being when the Leclanché cell is attached to the wire. We give a name to the whole situation by saying that an **ELECTRIC CURRENT** is flowing in the wire; the direction assigned to the current is purely arbitrary, and is by convention taken to be from the carbon of the cell along the wire back to the zinc pole. Other and better reasons will presently transpire suggesting that there is really a flow of some sort proceeding in the copper.

MAGNETIC FORCE AND ELECTRIC CURRENT.—If we make the wire very long and thin, so that it hangs in a loose loop, and join a strong battery to it, then the wire can itself be affected by the pole of a magnet, showing that, as always, action has its reaction, the magnetic force between magnet and electric current is exerted upon both. If the magnet's influence is brought to bear upon the bottom of the loop, as shown in the diagram, the motion of the wire marked by the dotted lines is perpendicular to its own length, and also to the direction of the magnetic force.

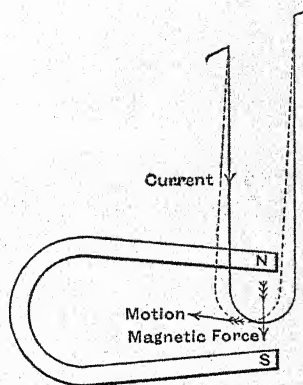


Fig. 221.—Motion of a Current under Magnetic Force

Any movable flow of electricity responds in this way to a magnet, and reversing *either* the magnetic force *or* the current reverses the direction of the motion.

ELECTROMAGNETS.—The magnetic action of a current-bearing wire can be magnified by coiling the wire into a spiral. Its magnetic force then acts along the direction of the axis of the spiral, so that the latter behaves like a magnet. If, for instance, the wire is wrapped around a ruler, the force is along the length, and we have a sort of bar magnet. If the whole could be bent into horseshoe shape, it becomes a horseshoe magnet. If the ruler is of iron, the magnetic influence of the current

magnetizes the core, greatly adding to the effect, and the result is the familiar electromagnet, bar or horseshoe as the case may be. The end from which the current, if visible, would seem to flow in the direction of the hands of a clock is the south pole.

IMPORTANCE OF ELECTROMAGNETS.—Electromagnets with good soft-iron cores and powerful currents may far exceed in strength any permanent steel magnet. Their importance in dynamos and motors, as the field magnets, will be more fully in evidence in the engineering section; but they

have a vast number of other uses, in electric bells, burglar alarms, relays, in telegraphy, in all kinds of small appliances connected with the automatic operation of current breakers and other electric machinery. In medical science the extraction from the eye of iron splinters is effected by a powerful electromagnet with a pointed pole brought close to the injured eye.



Fig. 112.—Eye Magnet

EDISON'S MAGNETIC-DEFLECTION SEPARATOR, employed in Norway, is a striking instance of the direct application to metallurgy of electromagnetism. The ore to be worked is a schist containing iron in the two forms of magnetite and hæmatite.

This is crushed in rollers to a powder, the grains of which are perhaps $\frac{1}{80}$ in. in diameter. The separator itself is a tower, some 75 ft. high, containing glass shelves placed alternately on its opposite sides, sloping downwards to their edges. The ore is lifted to the top, fed on to the upper shelf, slips thence on the next, and so on right down the tower. Opposite each step is an electromagnet whose pole pieces are bent round so as to act strongly on the ore. The uppermost magnets are comparatively feeble, and only deflect the most magnetic constituent of the ore, viz. the magnetite, which is swept into side tubes by the magnetic force and collected separately. The hæmatite and the non-feriferous material passes on from shelf to shelf, and next finds more powerful magnets awaiting it; these pull aside the hæmatite into other side pockets. If any garnets are mixed with the ore, their turn comes next, and finally the waste material falls out at the bottom.

TESTING INSTRUMENTS, such as galvanometers, ammeters, voltmeters, and wattmeters, frequently depend for their action on the magnetic effect of coils. In some galvanometers the coil is fixed and acts upon a compass needle, whose deflections afford a measure of the current flowing. In other types the coil *C* (fig. 113) is delicately suspended or pivoted and controlled by a flat metal strip or a spring *h*; it is placed between the poles *N* and *S* of a strong permanent horseshoe magnet, and consequently is deflected when a current flows around its turns. This type is much used in ammeters and voltmeters, the commercial instruments employed in the measurement respectively of the current (in amperes) and the electrical pressure (in volts) driving that current.

WATTMETERS measure the power, or rate of doing work, of the electric current; this is proportional both to the current and to the pressure, so the measurement is made by having one coil fixed and carrying the current, and the second coil movable and carrying a current always proportional to the pressure. The action between the two thus depends on both, *i.e.* upon the power that is to be measured.

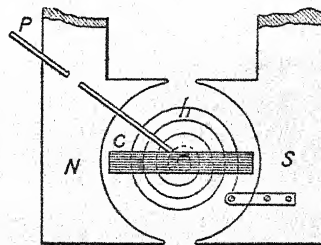


Fig. 113.—Weston Ammeter

The TELEGRAPH is essentially a long electrical circuit, which at one end is intermittently completed and broken by means of a key, while at the other end is some apparatus which signals the current in a definite "readable" fashion. This receiver is in practice a galvanometer, showing a deflection whenever a current passes through its coil.

The circuit may be of wire throughout, or the return wire may be dispensed with by connecting the ends of the line to earth, which completes the electrical continuity.

The simplest arrangement of sender is a DOUBLE KEY, so that the current may be sent in either direction; the galvanometer needle is then correspondingly deflected in either direction, one of which may signify a dot, and the other a dash, on the MORSE CODE. Thus words are spelt out by left- and right-hand signals, *e.g.* the name of the inventor of the code reads:—

M	O	R	S	E
Dash	Dash	Dot	Dot	
Dash	Dash	Dash	Dot	Dot
	Dash	Dot	Dot	

A modern set, known as WHEATSTONE'S ABC, very readily learnt and operated, spells the words out directly, letter by letter.

The current is an alternating one,¹ and only flows when a signal is being sent. The handle of a small alternator, turned by the operator, generates the current, and at the same time turns the pointer above and a connecting arm below the lettered dial of the sending apparatus, called the communicator. If the button of a given letter is depressed, this arm is stopped. A second arm connects the coils of the alternator through the line to the indicator, the receiving apparatus. This consists of two little electromagnets with a magnetized steel bar between them. This last is set vibrating by the continual reversals of the alternating current through the electromagnet coils. Springs tend to set a wheel rotating whenever the vibration occurs, but little movable stops prevent

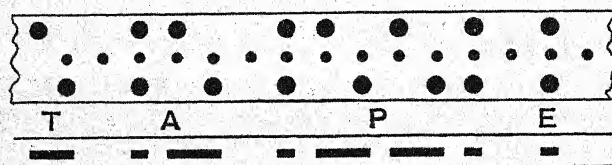


Fig. 114.—Tape Message

more than a small rotation at each oscillation of the bar. The pace is thus made quite steady, and a pointer is turned over a second dial, always keeping exactly in step with the communicator pointer.

Hence the operator merely turns the handle producing the signalling current, which also rings a bell warning the receiving station that a message is about to arrive. The bell is switched off till the message is completed. When the sending pointer is opposite the required letter its button is pressed, stopping the signal arm below, and so also the indicator pointer recording the same letter at the distant station.

The WHEATSTONE HIGH-SPEED AUTOMATIC TELEGRAPH has its messages previously "written" on long oiled-paper strips by punching holes in it on a Morse code, two opposite holes representing a dot, and two obliquely set a dash. This paper is fed by clockwork through a transmitter. In its essentials this is a machine sending alternating current by a little rocking lever, which makes contact to the line. When paper comes in its way this contact is prevented, so the perforated strip only permits current when the holes fall below the lever. The receiver writes down the signals by a little inked wheel, which, by the action of electro-

¹ i.e. surges to and fro in the wires carrying it, perhaps fifty times a second in each direction alternately. An alternator is a dynamo producing such currents.

magnets, is dabbled on to a second "tape" for short or long periods, marking dots or dashes. 400 or 500 words per minute can be transmitted in this way by the automatic telegraph; the general appearance of the perforated strip and written message is shown. The middle row of small holes in the first is merely the guide in running the tape through the sender, acting also as spacing between letters.

RELAYS.—In most telegraphic work the signalling current is too weak to directly operate the recording instruments, so a RELAY is used. This is a small electromagnet in the main circuit. When excited by the signalling current it attracts an iron spring, which closes a second circuit containing a battery of the necessary strength, the "local battery", and this operates the receiver.

DUPLEX TELEGRAPHY is the sending and receiving of messages simultaneously over one circuit. This is achieved by supplying extra coils in the sending apparatus, so that the current through them neutralizes the actual signalling current so far as the home-end receiver is concerned, though they do not affect a current from the distant station. **QUADRU- PLEX** telegraphy similarly allows for two currents each way along the same wire.

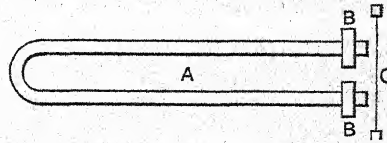


Fig. 115.—Telephone Receiver

TELEPHONES.—The simplest and earliest form of telephonic circuit consists of two ordinary telephone receivers joined by the necessary connecting wires. A receiver consists of a permanent horseshoe magnet A, upon whose poles are wound coils of wire B B. Just in front of the poles is a thin circular iron disc C supported around its edge. Sound waves falling upon it set it vibrating like the disc of Edison's phonograph. It alternately approaches and recedes from the poles, and so meets respectively more or fewer lines of force from the magnet. The force through the coils is thus weakened or strengthened, and induced currents are set up in them. They flow through the circuit and affect the coils of the second instrument. The magnetic poles of the latter are thus weakened or strengthened according to the direction of the induced currents, so the second disc is attracted more or less strongly, vibrates in exactly the same way as the first, and so sets up similar air waves, repeating the sound which first excited the action.

TRANSMITTERS.—Such an instrument, however, is now never used as a TRANSMITTER, though it is a standard type of RECEIVER. The transmitter acts on what is called the microphone principle, which may

be illustrated by three pieces of arc-light carbon. Attach to two of them wires joined also to a battery and a telephone receiver. Place

the two parallel to each other on a table, and complete the circuit by laying the third carbon across them. Then any slight noise made near this carbon "microphone" sets up vibrations, which shake the rods rhythmically into better and worse contact alternately, and so alter the electrical resistance of the circuit. The current thus fluctuates and causes the receiver to sound loudly, its vibrations being in time with the fluctuations, and so reproducing the original note.

A practical form of MICROPHONIC TRANSMITTER consists chiefly of small carbon granules contained between carbon blocks, one of which can be slightly adjusted by means of a screw, while the other is attached to a thin brass diaphragm. This, when spoken to, vibrates and presses with varying degrees of firmness upon the carbon granules, setting up periodic changes in their resistance. If, for instance, a note of frequency 1000 is sung into the transmitter, the resistance, and so the current, is caused to fluctuate 1000 times per second, and a note of the same frequency is sung out by the receiver.

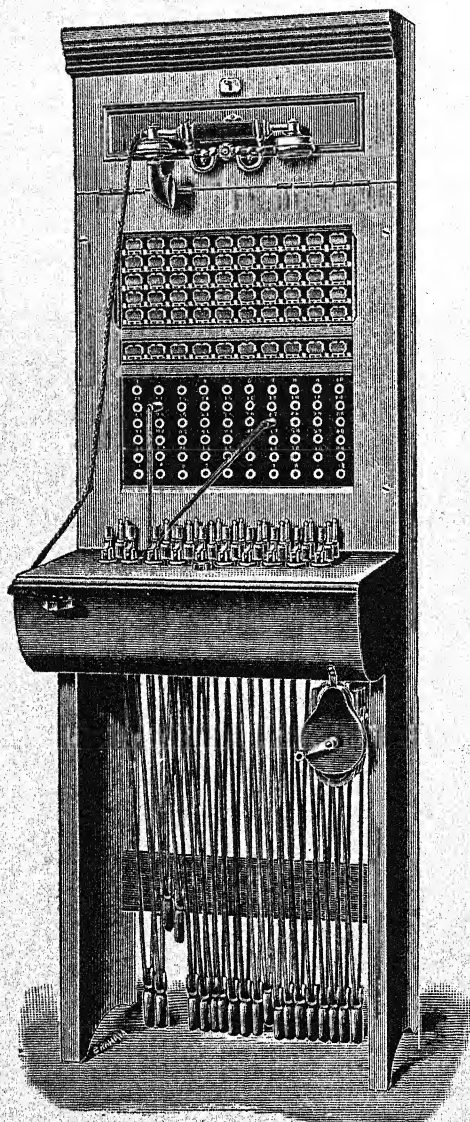


Fig. 116.—Telephone Exchange Unit

To summon attention, a bell operated by a magneto-alternator is added to the connections and worked over the telephonic wires.

SWITCHBOARDS at the telephone exchange put the subscribers into communication with each other. Within reach of the operator are plugs

and cords, one of each for each number in her charge, also "jacks", fittings to receive the plugs, one for every member's line. There is also a complete telephone instrument, magneto-alternator included, with its own plug and cord. A subscriber rings up, an indicator showing his number; the operator puts the exchange plug into the subscriber's jack, and learns the number he requires. Then the exchange plug is put into the jack of the "wanted" line, and connection made with the exchange; finally the "wanted" plug is put into the enquirer's jack, and the two numbers are in communication until "ring off", when withdrawal of the plug completes the transaction.

CHAPTER XII

ELECTRIC COOKING—ELECTRIC FLATIRONS— ELECTRIC LIGHTING—ELECTRIFICATION AND ELECTRICAL MACHINES

UTILIZATION OF ELECTRIC HEAT.—The heat produced by the flow of electricity is used in electric radiators, cooking stoves, flatirons, and for other domestic purposes.

ELECTRIC COOKING.
—A complete and well-finished cooking outfit may cost about £25, and will spend 3*d.* where a gas stove would not cost much above 1*d.* The great advantages of electric cooking at present lie in the entire freedom from fumes, extremely quick rise to full cooking temperature, and perfect control.

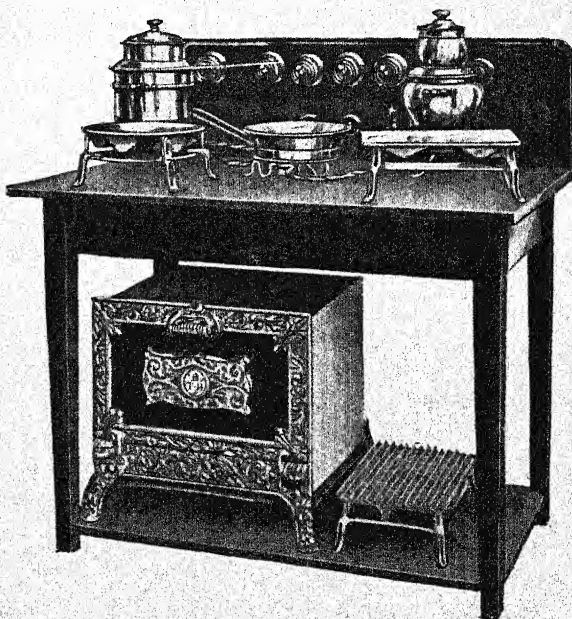


Fig. 117.—Electric Cooking Stove

The various utensils are heated by coils of wire fixed in their bases,

flat coils under frying pans, cartridge-shaped coils in the walls of ovens, and so forth.

ELECTRIC FLATIRONS are similarly heated, the coils being so arranged

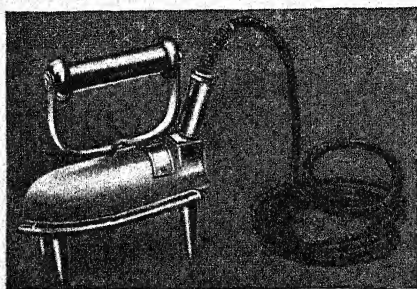


Fig. 118.—Electric Flatiron

that the iron quickly takes up a temperature about that of boiling water, which never varies so long as the current is kept on. The necessary connecting wires are long and flexible, so as in no way to interfere with freedom in ironing, and run from a wall plug like those of removable electric lamps.

however, that the heat produced by the current finds its most important present uses.

The electric GLOW LAMP consists of a glass bulb from which air has been as far as possible removed by powerful air pumps, containing a fine filament through which the current flows, thus raising it to a bright white

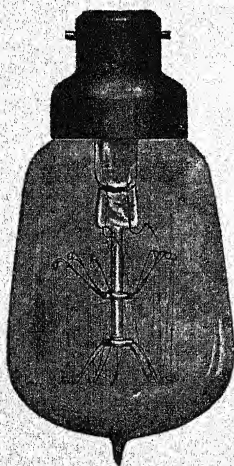


Fig. 119.—Tantalum Lamp

heat; it consists, in the ordinary lamp, of a carbonized thread prepared by many stages of a most ingenious process from bamboo fibre or from cotton wool. Instead of carbon, a few new kinds of lamp use tantalum or osmium, two of the rarer metals. These are in the form of long thin wires zigzagged up and down the globe over little insulating brackets. Their manufacture for use with the higher voltages and with alternating current involves difficulties which have not yet been thoroughly overcome; but for direct current at ordinary pressures their "life" is quite satisfactory, and they have the advantage that if the wire is broken in one place the fractured length will fall into contact with the next strip, and the lamp may still be used without appreciable loss

of brightness. The first cost is high, 4s. or 5s.; but this is more than compensated for by the far lower cost of current, at the rate of $1\frac{1}{4}$ to $1\frac{1}{2}$ watt per candle as against $3\frac{1}{2}$ or so for the carbon glow lamp.

The NERNST LAMP similarly glows white-hot under the passage of a current; but in this case the "glower", a rod made of refractory earths of rare metals, thoria and the like, only conducts electricity when hot. So a

supplementary device has to be added, a small gas flame in some cases, but more commonly a little encircling coil of wire through which the current is first switched; by this the "glower" is heated until it conducts, when the gas or heating coil is automatically switched off.

The ARC LAMP consists of two rods, usually of carbon. These are at first brought into contact so that a current passes from one to the other, strongly heating their tips. They are then drawn apart, and the discharge continues to pass as a sort of flame carried by carbon vapour. In ordinary arcs the light comes chiefly from the glowing end of the positive carbon, *i.e.* the one from which the current passes to the vapour of the gap. This positive carbon is therefore the uppermost, so that the light is thrown downward. Some lamps use carbons impregnated with metallic salts which lend a brilliant yellow colour to the arc itself, which then becomes the chief source of the light. In these frequently the carbons, instead of lying end to end one above the other, are set side by side, the lower ends nearest each other. The arc is then kept at these lower points by the action of a magnet; the flame, being a movable current, is easily directed by the magnetic force.

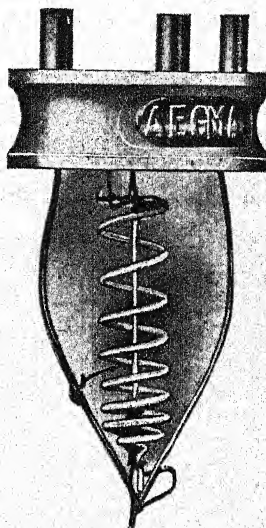


Fig. 120.—Nernst Lamp

In all cases the closing of the carbons to start the current, the drawing apart to form the arc, and the regulation of its length as the rods burn away is all effected by electromagnetic or clock-work devices in the frame of the lamp. An arc lamp consumes far more current than a glow lamp, and is only suited for the illumination of wide spaces, such as not too narrow streets and the larger halls. It is more economical in watts per candle-power than glow lamps.

The MERCURY-VAPOUR LAMPS, so well adapted for factory or photographic use, give such a ghastly pallor to the face that until some improvement in their red radiation is brought about they cannot be considered as house illuminants. They are almost entirely lacking in red rays, so that the pink of cheeks and lips finds no light to reflect, and perforce appears blackish in hue.

On the other hand, this freedom from red saves much fatigue of the eyes, and the lamps are thus excellent for office work; the great actinic power of the light renders them useful as a daylight substitute for photographers. Their cost per candle-power is low, and their life satisfactory.

Their light is produced by the passage of the current through the vapour of metallic mercury in an otherwise evacuated tube. The vapour is not glowing because it is white-hot, but because of electrical disturbance; it is, in fact, a bright vacuum tube. The freedom from loss in heat is the cause of the low cost of working. In ordinary lamps where some solid or vapour is heated to incandescence it is only a residuum of the energy we spend that comes back as light, all the heat *as* heat is wasted; it is only the glowworm and its kind that has as yet found the perfectly heatless illuminant.

ELECTRIFICATION.—To return from electromagnetism and the electric current to electricity pure and simple, we find another set of attractions not exhibited by ordinary substances, those of ELECTRIFIED BODIES, such as a dry glass rod rubbed with silk, ebonite or sealing-wax rubbed with fur, and so forth. This time it is not iron only which is attracted, but any substance, though of course the effect is only evident with quite light or delicately pivoted bodies. The temporary peculiar state of the rubbed bodies is termed ELECTRIFICATION, or charging with electricity; we shall later see the likeness to the electricity of the current of a Leclanché cell.

The electricity of a silk-rubbed glass rod is of different kind from that of fur-rubbed ebonite or sealing wax. The two rods attract each other, but repel electricity of the same kind as their own; thus two similar electrified rods show repulsion. The electricity on the glass is called positive, that on the wax negative.

One kind can never be produced without the other; the silk rubber of the glass has a negative charge, the fur after friction with the wax remains positively electrified. Defining equal charges as those which in similar circumstances produce equal forces of attraction or repulsion, we find that equal and opposite charges exactly annul each other's effects, and if imparted one after the other to the same body leave it quite uncharged.

INSULATORS.—A metal cannot be electrified by friction in the simple way described for glass or ebonite, but if mounted on a glass handle it can be thus charged by rubbing with fur. The difference evidently lies in the ease with which the electricity escapes through or over the metal, which is therefore termed an electrical conductor. Glass, ebonite, &c., do not thus conduct, and are called INSULATORS.

ELECTRICAL MACHINE.—By producing electrification on a larger scale by means of an electrical machine, we may show that its escape along a conductor exhibits the effects we noticed in a wire joined to the poles of a Leclanché cell. Passed through a wire, the electricity deflects a compass needle, or can magnetize a piece of iron around which the wire is lapped.

We have a true electric current, and a comparison of the effects shows that in the Leclanché experiments the current consists either of a flow of positive electricity in the wire from carbon to zinc, or of negative in the reverse direction, or of both these effects together. Later we shall see that the second view is the correct one, that the negative flow is the one actually occurring in a wire.

A charged glass rod holds the electricity in a state of rest. It exerts

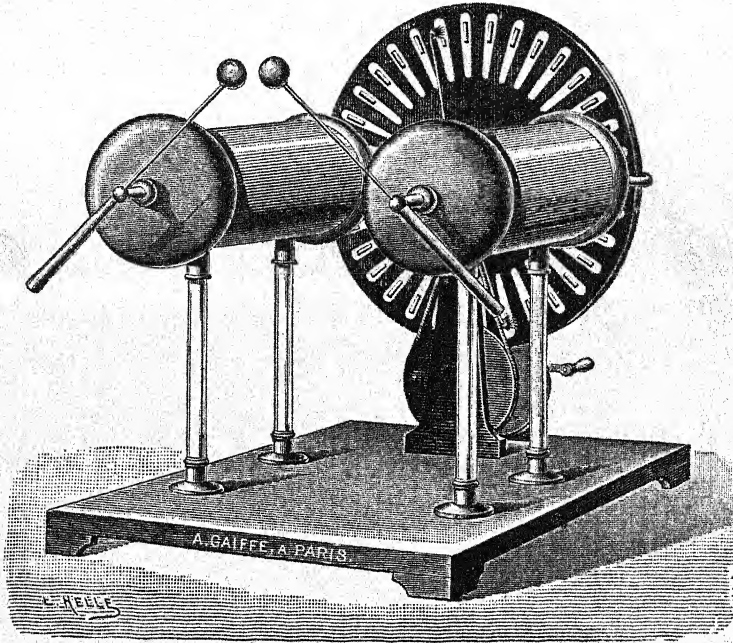


Fig. 121.—Electrical Machine

its forces of repulsion on any other positive charge brought near it, and of attraction on any negative charge.

The ELECTRIC CURRENT exhibits the same electricity in motion; the attractive and repulsive forces are no longer evident, but are masked by the more powerful magnetic effects produced by the motion. This magnetic force acts in circles around the line of motion of the electric current, related to the direction of flow of the positive kind as the twist of an ordinary screw is to its lengthwise motion. In particular, the heat produced by the passage of the current shows that energy is concerned in moving electricity through a conductor, as in moving matter through a resisting medium; this electric production of heat suggests some similar frictional resistance.

CHAPTER XIII

INDUCTION COIL—VACUUM TUBES—CATHODE RAYS—CONSTITUTION OF MATTER (IONS, CORPUSCLES, AND ELECTRONS)—RÖNTGEN RAYS

So far we have found nothing to shed light on the nature of electricity, but its passage through gases gives us many clues.

ELECTRIC SPARKS.—An electrical machine or the apparatus known as an **INDUCTION COIL** (p. 76) can drive electricity across an air space in the form of sparks; these are frequently of wavy or branched form, are accompanied by the production of a good deal of heat and a sharp crackle

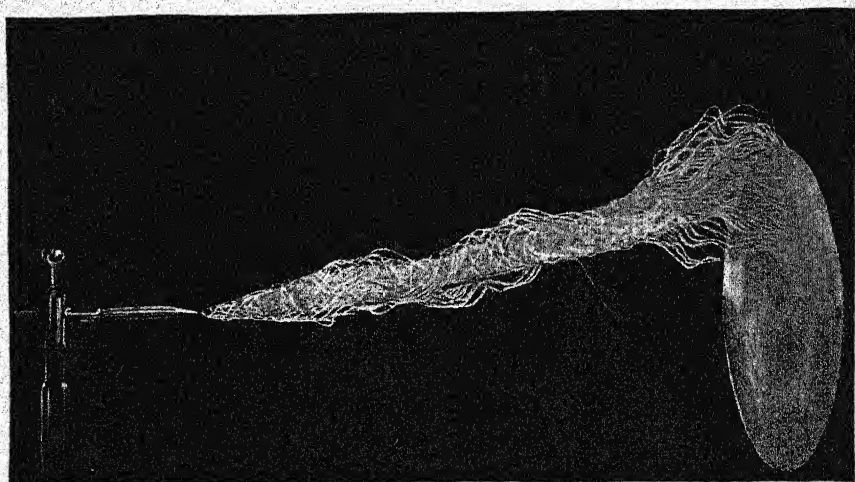


Fig. 122.—Electric Spark in Air

due to the sudden sound pulse flung out into the air by the violent disturbance of its molecules. **LIGHTNING** is Nature's production of the electric spark on a large scale, **THUNDER** her Gargantuan version of its crackle, complicated into rolling sounds by reflection of the sound pulses from clouds or unequally dense layers of air.

VACUUM TUBES.—This spark discharge which occurs under ordinary pressures is profoundly modified by rarefying the air. We can study these changes if we pass the spark between metal wires or plates (called the **ELECTRODES**) at the ends of a glass tube attached by a side tube to a powerful air pump. If the tube is a foot or so long, the spark may at first be unable to pass unless our electrical machine is very powerful; but as

the air is gradually pumped out, the discharge commences in the form of stringy wavering sparks of a violet tint. These become more and more vague in form as the exhaustion of the tube is continued, and presently the tube is lighted up by a violet glow of somewhat uneven brightness, the space about the negative electrode (the CATHODE) being dimmer than the rest of the column. As the pump proceeds to remove more air the colour changes first to a redder tint, and then becomes white and milky. The light, too, is seen to become discontinuous, the tube seeming to be packed with alternate bright and dark discs, called the striations, which waver to and fro lengthwise over a short distance. A dark space, called Faraday's, appears in front of the cathode, and spreads gradually along the tube. Presently the glowing cap which surrounds the cathode breaks away and passes up the tube, separating the Faraday dark space from a second which now appears, the Crookes dark space. About the same time the walls of the tube at the same end begin to glow brightly or fluoresce with green wavering light. (Some kinds of glass fluoresce red.) The Crookes darkness grows as the vacuum gets higher, and eventually fills the whole tube, which now also fluoresces at the end opposite the cathode, but is otherwise dark. One might suppose that the phenomena of the discharge have ended; on the contrary, the most striking and remarkable effects of all are obtained in the dark space. A solid object set in the tube throws a sharp shadow, shown by a dark patch in the midst of the green fluorescence in a straight line beyond. It is noteworthy, too, that this fluorescence itself always faces the cathode, wherever the positive electrode (ANODE) may be placed (*e.g.* fig. 123).

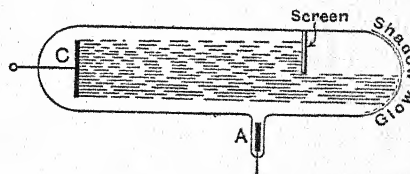


Fig. 123.—Vacuum Tube

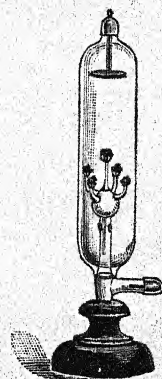


Fig. 124.—Fluorescence of Gems in Cathode Rays

An object in the tube becomes heated, sometimes even red-hot. Many substances, notably precious stones, light up brilliantly, with gorgeous fluorescence. A small lightly pivoted windmill is driven round with great speed if one side is screened from the cathode. Thus energy is associated with the dark space, vigorous actions of some kind are proceeding within it, and their source appears to be at the cathode.

FOURTH STATE OF MATTER.—We cannot enter into the history of the discussions as to what these actions are. Sir William Crookes, who

first investigated them, guided by the sharp straight-thrown shadows and the mechanical forces, almost alone hazarded the opinion that particles of some sort were being flung out from the cathode and were rushing in

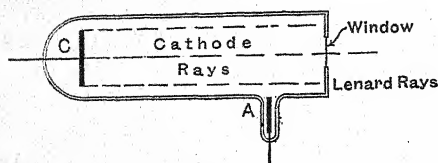


Fig. 125.—Cathode and Lenard Rays

straight paths along the tube. These particles he supposed to be atoms of ordinary matter, in an ultra-gaseous or fourth state, driven along with great speeds by the electric forces.

the action that these cathode rays, as they are called, can pass through a thin aluminium window forming the end of the tube opposite the cathode. Outside the tube they are termed Lenard rays, after the scientist who

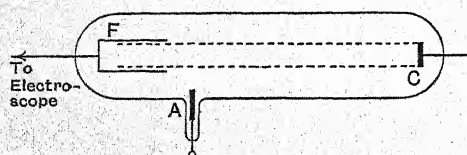


Fig. 126.—Testing Charge of Cathode Rays

CATHODE RAYS.—So violent is the action that these cathode rays, as they are called, can pass through a thin aluminium window forming the end of the tube opposite the cathode. Outside the tube they are termed Lenard rays, after the scientist who discovered this penetrating power of the high-vacuum discharge; they are in no way different from the rays inside the tube.

Later research shows that the cathode rays are not composed of flying *atoms*, but in other respects bears eloquent testimony to the truth of Crookes's daring theory.

Whatever the rays are it was soon found that they carry negative electricity. If opposite the cathode is placed a metal cylinder *F* (fig. 126), communicating by a wire sealed through the glass with an electro-scope,

this latter is found steadily to collect a negative charge brought by the rays to the cylinder.

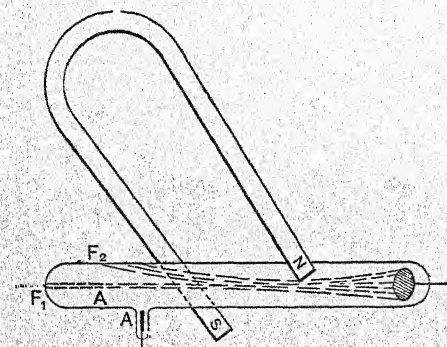


Fig. 127.—Magnetic Deflection of Cathode Rays

The theory that the phenomena are due to some sort of ether waves, like light, is contradicted by failure to obtain reflection or refraction in any way.

DEFLECTION OF CATHODE RAYS.—Another crucial discovery is that a magnet deflects the rays, as shown by the motion of the

green patch of fluorescence upon the glass from F_1 to F_2 . This at once suggests a movable electric current or stream of electricity, and the deflection, indicated by the dotted lines, shows that the flow from the cathode consists of negative electricity.

Electric force also deflects the stream, two plates X and Y, charged respectively positively and negatively, moving the stream into the form shown by broken lines (fig. 128); this again proves the existence of negative charges.

IONIZED GAS.—Before we enquire more closely into the nature, size, and mass of the carriers of this negative electricity, termed **CORPUSCLES** by Professor J. J. Thomson, let us glance at a few other methods of producing electric charges in gases. Air and the others in their ordinary state are very good insulators, but can be made to conduct comparatively well in several ways. Combustion is one; the gases of a flame are quite good conductors, so is the air near a white-hot metal or carbon surface. The X-rays (of which more later) passed through air leave it in a conducting state, and the passage of a beam of ultra-violet light (for instance, from an arc lamp) has the same strange effect. The conducting power lasts for some time, but is speedily destroyed by filtration through cotton wool or by electric force. If the air lies between two plates, one connected to an electroscope and the other strongly and negatively charged, it speedily regains its insulating power, and at the same time a negative charge appears on the electroscope. An equal positive charge appears in the same way if positive electrification replaces negative on the charged plate. These charges cannot represent a leak through the air from the charged plates, for the recovery of its insulating properties could not be thus explained; the charges are the source of the previous conducting power of the gas, which when it contains such charged particles called **IONS** is said to be ionized. An **IONIZED GAS** then consists of ordinary uncharged molecules and these ions, some positive, some negative, the two amounts of electrification being equal.

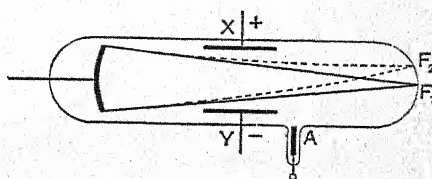


Fig. 128.—Electric Deflection of Cathode Rays

J. J. THOMSON'S RESEARCHES ON ELECTRIFICATION AND MASS OF IONS.—How can we measure the electrification and the mass of these charged particles? The first step perhaps is to estimate their number, and this was done by J. J. Thomson acting on the discovery made by C. T. R. Wilson, that the corpuscles can condense water vapour from air upon themselves as nuclei, behaving like the dust particles of Aitken's experiments previously described.

SIZE, SPEED, AND NUMBER OF IONS.—By ionizing dust-free moist air in a glass vessel by means of ultra-violet light or X-rays, and then allowing it to expand suddenly into another vessel, Prof. Thomson cooled

the vapour sufficiently for it to form into tiny water drops upon the ion nuclei; the drops sink slowly, very slowly, because the air buoys such minute particles up like the smallest droplets of a Scotch mist. Knowing the amount of moisture present, and the degree of expansion allowed, Thomson was able to calculate the total quantity of water deposited. If then he could find the size of each drop, the number could at once be calculated, *i.e.* the number of ions present to cause the condensation. Now the SIZE is known from the rate of fall, for the smaller the drops the slower their motion, and a mathematical formula gives the precise relation between size and speed. The SPEED was measured directly, for the cloud of drops had a sharp upper surface which was watched through a telescope as it sank down. We have then the data for finding the size of the drops and so for estimating their NUMBER. Let this be N .

CHARGE OF IONS.—A separate measurement was next made to determine the CHARGE of the ions, *viz.* the experiment above mentioned in which a charged plate drives the electrification to an electroscope. If Q is this total quantity and e the charge of each ion, then evidently e is obtained by dividing Q by N , the number of ions. This for either positive or negative carriers proves to be .0000000034 electrostatic units¹, *i.e.* 3.4×10^{-10} units. This number proves of the utmost importance in electric theory, constituting what appears to be a sort of atom of electricity, an indivisible fundamental unit.

MASS OF IONS.—Another step gives us the MASS of the particles carrying these charges. In gases at ordinary pressures the result shows that several atoms may be collected together in an ion, which therefore doubtless consists of a positively or negatively charged particle acting as a nucleus attracting uncharged atoms. If the pressure of the gas is diminished, however, these atomic bundles seem to break up and the ions more and more approximate to the simple charged nuclei which are at the root of the matter. And now, in very high vacua, striking differences begin to appear between the positive and negative ions, the positive proving to have the same mass as a hydrogen atom, while the negative is about 1700 times lighter, *i.e.* is a particle of matter nearly two thousand times less in mass than the lightest known atom of matter. Exactly the same value has been deduced for the corpuscles or negative carriers of the cathode rays, and we are left to face the astounding fact of the existence of matter in so fine a state that an atom of average mass is by comparison as a ton is to an ounce.

¹ An ELECTROSTATIC UNIT CHARGE is that which repels such another charge 1 cm. distant with a force of 1 dyne (about 1 mg. weight).

METHOD OF RESEARCH.—The method by which these striking results were obtained has already been suggested. A movable current under the action of magnetic force moves at right angles both to its own line of flow and to the direction of the force. The negative carriers moving as in the cathode rays are similarly bent from their straight path, and the bending is proportional to the magnetic force and to the strength of charge of a carrier. But the faster the particle and the greater its mass the less is its path bent. Summing these facts up, we can form a mathematical expression connecting the charge, mass, and velocity of the particles and the strength of the magnetic field on the one hand with the curvature of path produced on the other. Of all these quantities only the mass of a particle m and its speed v are unknown, so the quantity mv can be calculated. The curvature was determined by the change in position of

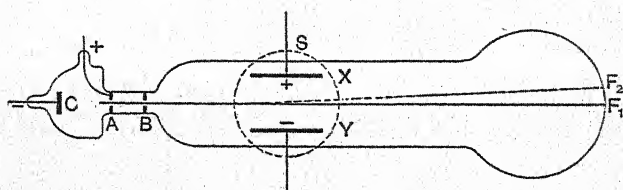


Fig. 129.—Mass of Corpuscles (Electrons)

a spot of fluorescence at F, produced by cathode rays passed successively through two narrow slits before coming under the influence of the magnet, as shown.

Thomson next estimated the speed of the corpuscles by a modification of the method. Keeping the magnetic field as before, he applied an electric field also by charging up the plates X and Y (fig. 128), positively and negatively as marked. The negative particles are thus attracted upwards by X and repelled by Y in the same direction to such a direction as F_2 ; by adjusting the strength of the magnet poles we can just bend the rays back into a straight line again to F_1 .

Thus we get a new expression involving the electric force which is also of known strength. Between our two formulæ we can separately find both v , the speed of a corpuscle, and m , its mass. The former proves to be variable, averaging about 20,000 miles per second or one-tenth of the speed of light. The mass of the negatively charged corpuscle is 6×10^{-28} grm., *i.e.* 6 ten-thousandths of a billionth of a billionth grm., the quantity alluded to, about 1 seventeen-hundredth part of that of the atom of hydrogen.

This value is quite independent of the pressure in the tube, of the way of producing the corpuscles, of the material of the electrodes, and of the

kind of gas employed. Air, oxygen, hydrogen, carbonic acid gas, all give us identical corpuscles, which thus appear to be a constituent of all matter alike, a modern realization of old alchemistic dreams of the unity underlying all material bodies.

ELECTRONS.—The usual name for these negative corpuscles is ELECTRONS. In an ionized gas they are the nuclei of the negative ions, in cathode rays they move alone. All substances seem to contain them, the vapours of metals behaving in a vacuum tube exactly as do the ordinary "permanent" gases.

POSITIVE ELECTRICITY.—The positive ions, even in high vacua, appear to be bulkier entities of atomic size. In the cathode rays they are absent, but Goldstein discovered a positive stream corresponding to the negative one in the space behind the cathode. He cut holes or canals through the metal to permit their passage into this part of the tube, which is comparatively secluded from the bustle of the negative electrons. From this mode of examining them he called them CANAL RAYS, an epithet not very

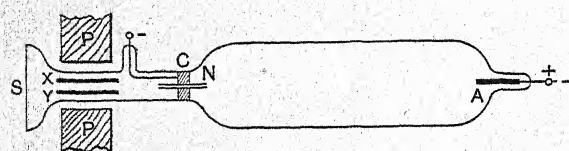


Fig. 130.—Apparatus for Investigating Positive Ions

enlightening as to their nature or properties.

Wien and J. J. Thomson have since sought to discover the secret of the structure of these

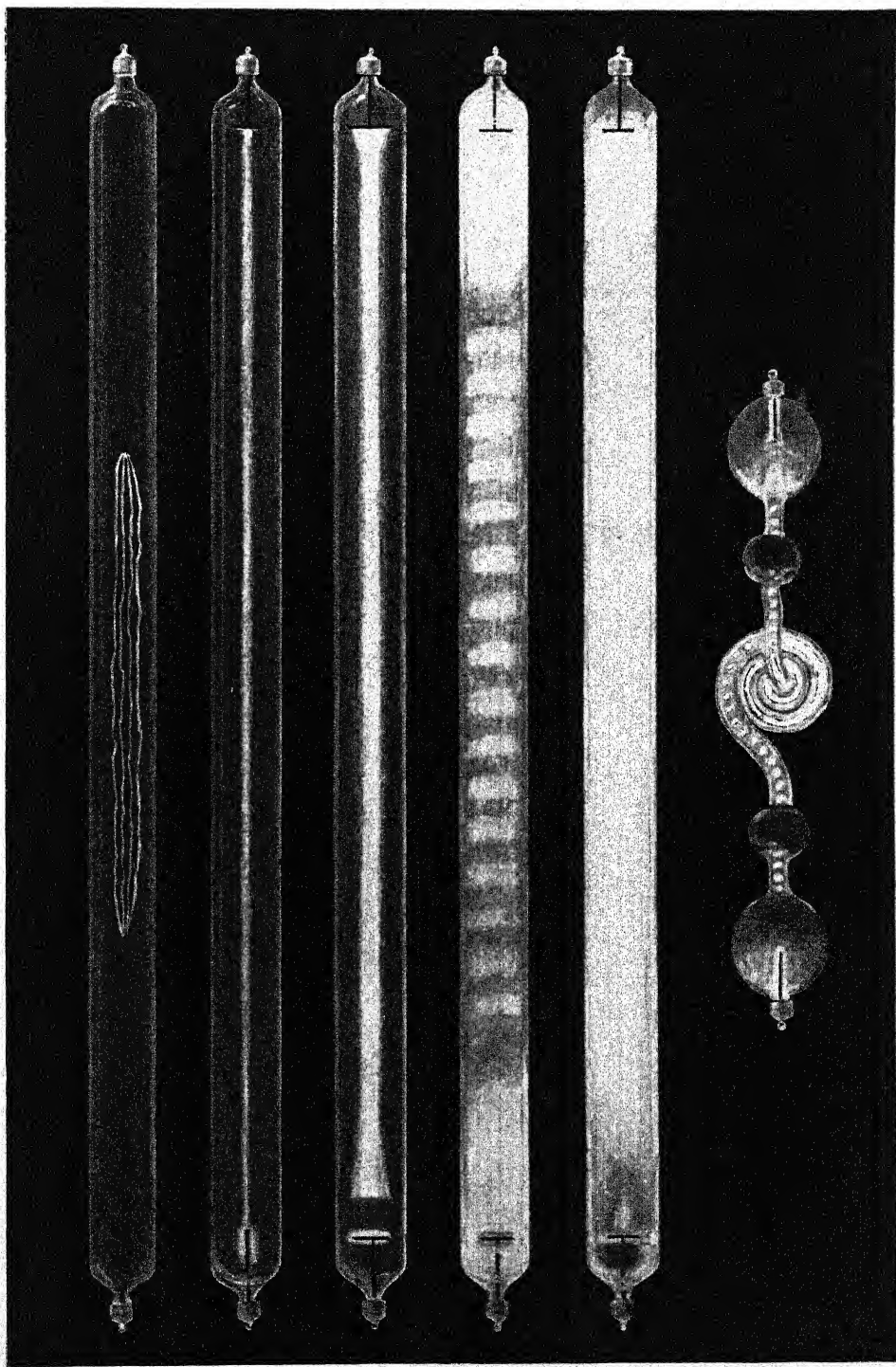
bodies. The unanimous verdict is that the positive carriers are more massive than the negative, and may have many times the mass of a hydrogen atom. However, working with conditions as to high vacuum strictly similar to those under which the cathode rays have been investigated, J. J. Thomson has arrived at comparatively simple and very striking results.

APPARATUS FOR INVESTIGATION OF POSITIVE IONS.—The diagram (fig. 130) illustrates the form of tube employed. PP represent the poles of a powerful magnet which deflects the rays; XY metal plates, which, when oppositely charged, also deflect them by electric force. C is the cathode in the form of a cylinder pierced by N, the fine hollow needle of a hypodermic syringe. Through this narrow passage the positive rays stream from the anode A, and their deflection is observed by aid of the screen S, which is of glass coated with Willemite, a substance which fluoresces brightly when the rays fall upon it. The fluorescence due to the narrow pencil of rays passing through N is in the form of a small bright spot at the middle of S; when the magnet acts on the rays, or when the plates XY are charged, this spot moves because of the bending produced in the course of the rays. Cal-

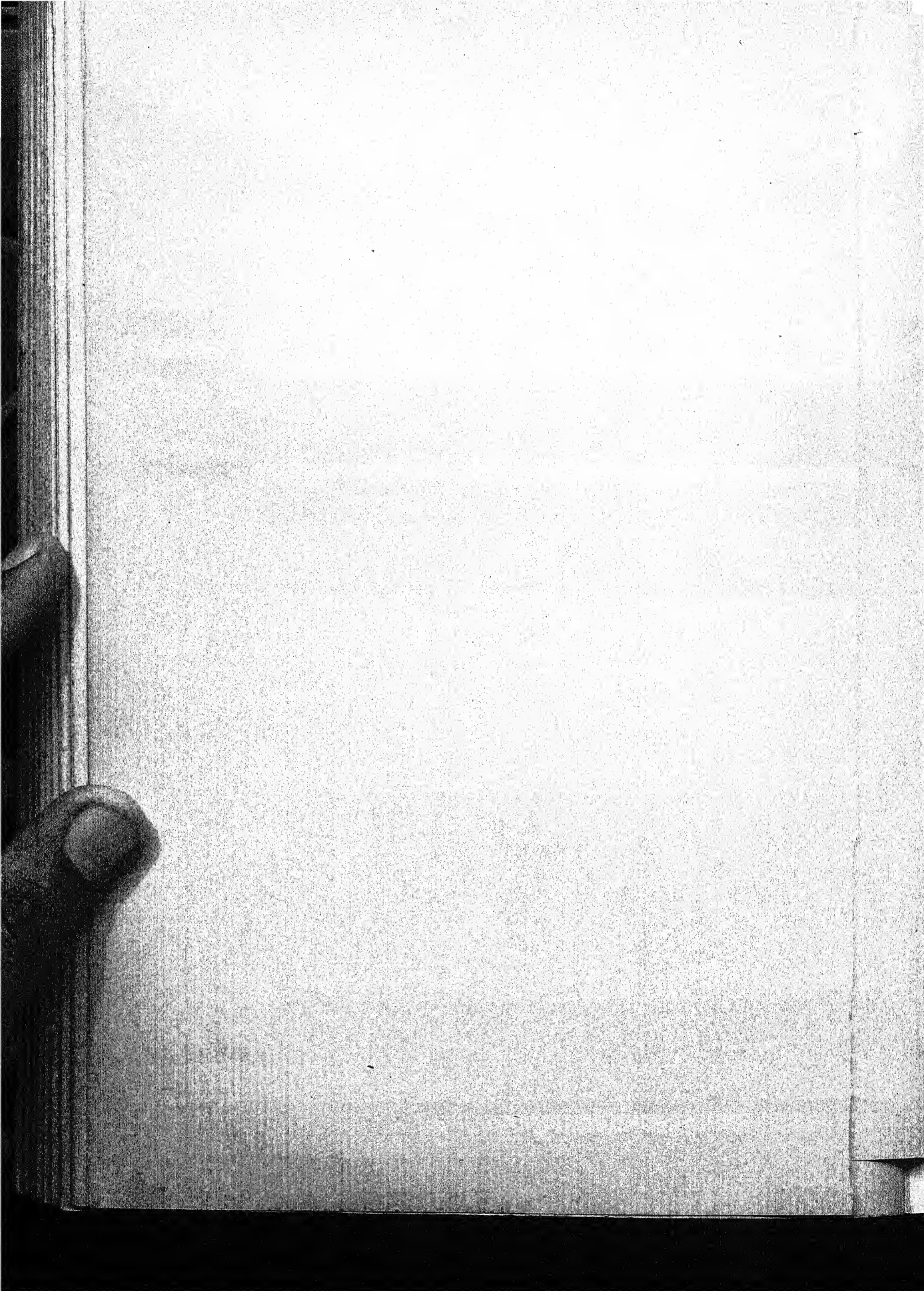
ELECTRIC DISCHARGE IN AIR

Showing the changes as Air is gradually pumped out of the Discharge Tube (1-5).

- 1, Sparks in Slightly Rarefied Air.
- 2, Longer Continuous Column of Light.
- 3, Column broader and detached from Cathode.
- 4, Appearance of Striations.
- 5, Further extension of Cathode Dark Space (Crookes Vacuum).
- 6, Vacuum Tube, showing Striations and Fluorescence Colours of Glass.



ELECTRIC DISCHARGE IN AIR
SHOWING THE CHANGES AS AIR IS GRADUALLY PUMPED OUT OF THE DISCHARGE TUBE (1-5)



culations made as with the similar cathode-ray experiment show that the mass of a particle is distinctly less than that of an atom of the gas in the tube (air, argon, helium, and others were used). Two or even three sets of carriers appear to exist, shown by two or three separate bright spots when the rays were deflected. The lightest have the mass of the hydrogen atom, the others twice and four times that mass, and this quite irrespective of the kind of gas filling the tube.

The carriers of positive electricity in these high vacua are not then electrons, but appear to be atoms of hydrogen or (for the heavier kinds) of helium, even though no hydrogen or helium is originally present in the tube. The same result as we saw was obtained for the positive charges in high vacua in air ionized by X-rays or ultra-violet light.

SUMMARY OF EVENTS TAKING PLACE IN VACUUM TUBE.—Let us return now to the discharge of our vacuum tube and sum up our conclusions relating to it. When electric force is applied by our electric machine between the anode and cathode, a discharge is produced because of the few stray charged particles or ions which seem always present in gases, especially under low pressures. These ions are driven, the positive to the cathode and the negative to the anode. The great electric force and the extreme lightness of the particles conspire to produce great speeds, and by the force of their impact on the air molecules in their way, or, finally, upon one of the electrodes, they loosen more ions from the gas or metal. These electrons are repelled by the similarly charged electrode; let us take the cathode to make the description definite. The electrons which are here formed rush away in straight lines, and if no more were formed to take their place the discharge would cease. But the action is continually maintained by the impact of the attracted positive ions, which were themselves liberated from the anode by the electrons. A sort of mutual rescue from the imprisonment of the electrodes is going on. The electricity which is thus carried by the flying ions makes up the current through the gas; in low vacua the carriers are electrons or positive corpuscles, as the case may be, attached to one or more atoms of the gas, which are thus dragged to and fro.

If the vacuum is improved the ions find fewer gas molecules to obstruct their careers, move faster and faster, and ultimately tear themselves free from their load of neutral atoms, flying alone with enormous speeds. In the case of the negative electron especially, of such minute mass, the velocities become comparable with that of light itself. Electrons leaving the cathode travel an appreciable distance without meeting an obstacle, so no light or other phenomenon appears, and we have a

dark space around the cathode. When the little projectiles meet gas molecules these are violently disturbed, and some are split up or ionized; light is produced by the great amount of energy "lost" in the collision. The newly formed electrons travel on under the electric forces, and if the vacuum is high enough, may have gone some distance before they in turn strike other gas molecules, which are broken up and repeat the performance. So with moderately high vacua we get alternating bright and dark striations, as already mentioned.

If the vacuum is very high, the electrons flung off by the cathode may be able to traverse the whole tube's length without encountering other obstacles, and then the Crookes dark space fills the tube, and fluorescence only appears on the glass at the farther end, which the

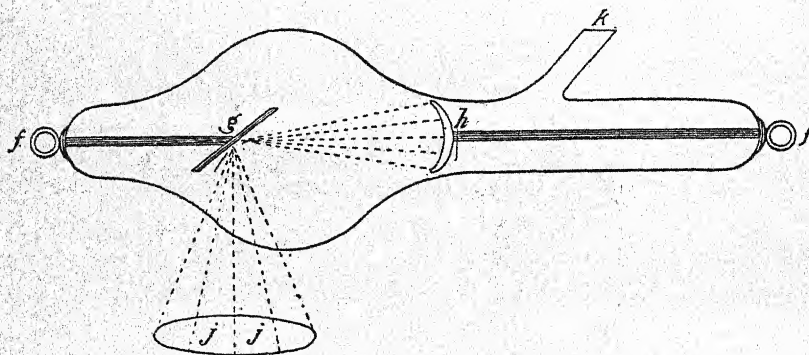
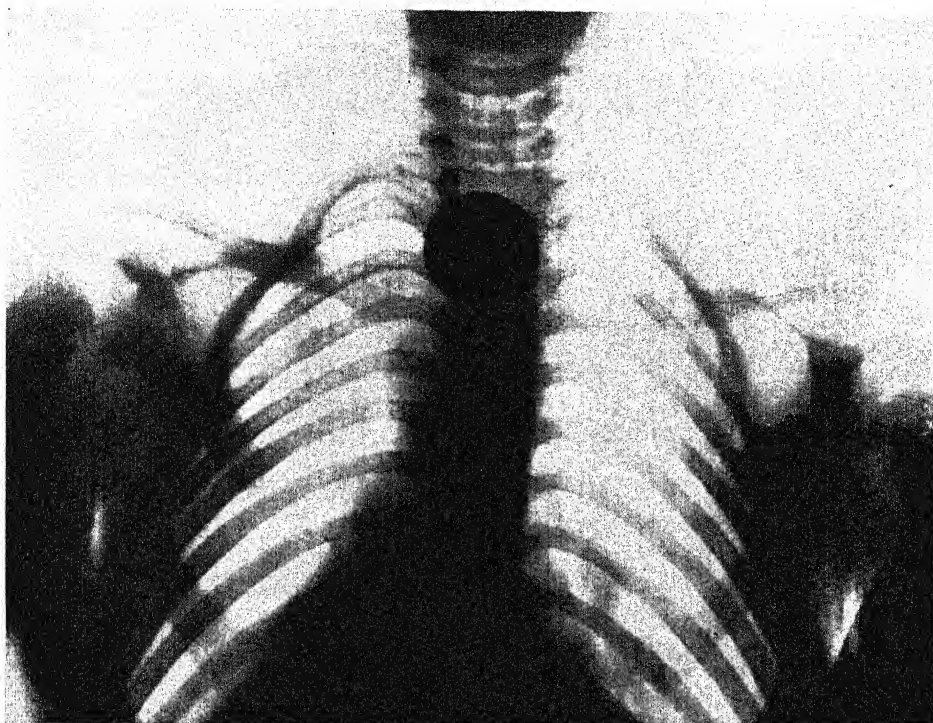


Fig. 131.—Röntgen-rays Focus Tube

electrons are bombarding. If a metal plate comes in their way, however, they are stopped, a shadow is thrown on the glass, and the energy of their motion is wasted in heat, just as when a bullet strikes a target. If the plate has not many or massive molecules to oppose to the flying corpuscles, they may be able to pierce through it, as in the thin aluminium foil of Lenard's "window".

Now, when a rifle bullet strikes a metal target, in addition to the energy spent as heat some is used in producing air waves, causing the sound of the impact. The shock upon a massive target, which cannot vibrate freely as a whole, produces a sharp single pulse of sound rather than a series of waves, a click rather than a musical note. Boys has photographed the pulse when a glass plate shatters under the blow.

RÖNTGEN RAYS.—Is there nothing analogous to this sound pulse produced when an electron strikes and is stopped by a massive molecule such as those of a platinum plate? The sort of thing to be expected is a sudden single pulse in the ether, like a solitary quickly vibrating light



HALFPENNY IN CHILD'S GULLET

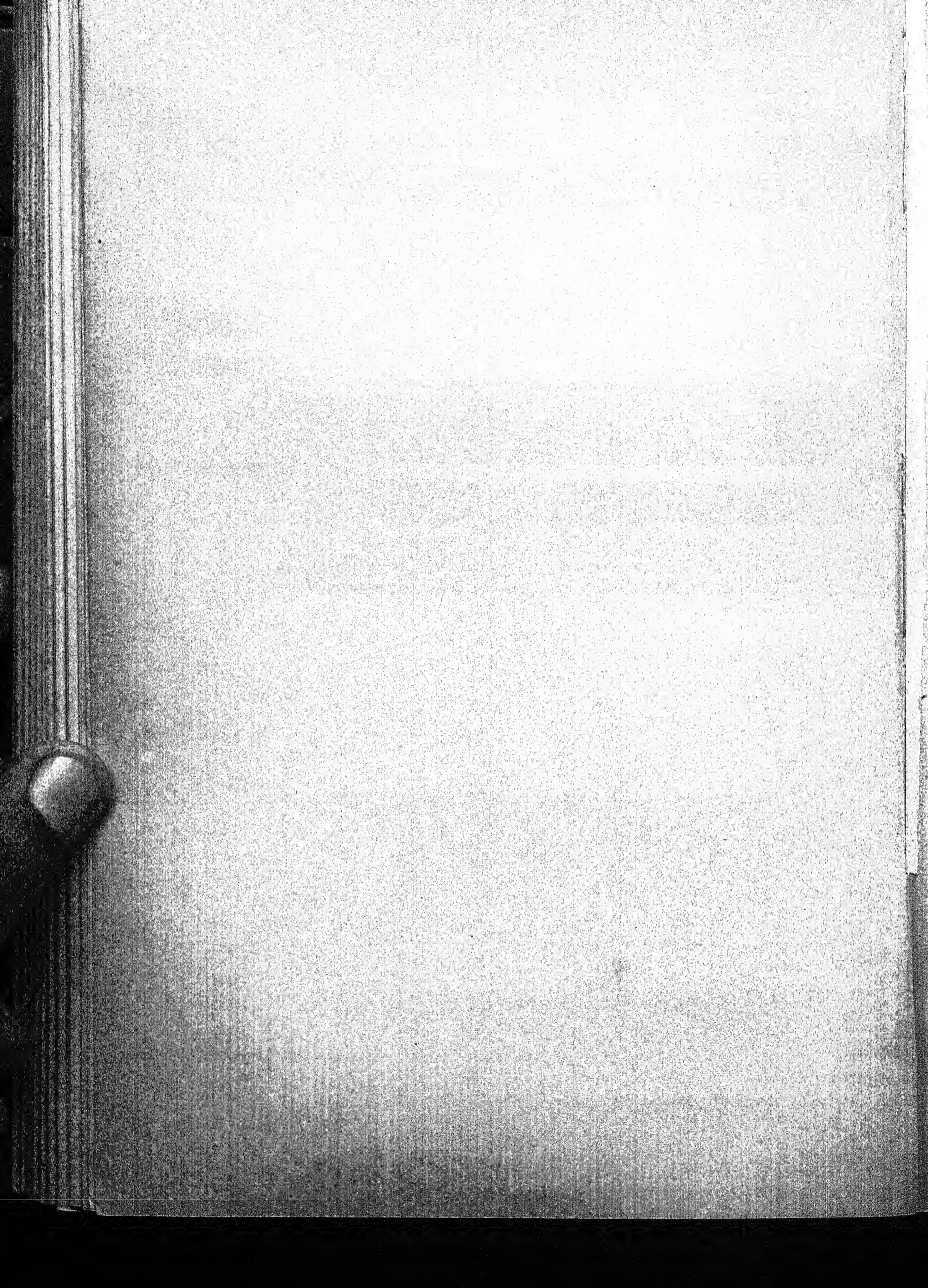


NEEDLE IN THUMB



BROKEN FINGER-TIP

RÖNTGEN-RAY PHOTOGRAPHS



wave. The familiar X-RAYS, discovered in 1895 by Röntgen, are those pulses, true ether waves, very quick in their vibrations, not in regular trains, but flung out as a mixed bundle of radiation, as it were, by the numberless impacts of the electron stream. The X-ray tube is simply a high-vacuum tube with a platinum plate, sometimes called the anti-cathode, set obliquely in the path of the cathode rays. From this plate proceed the X-rays, penetrating the glass of the tube, and also, as everyone now knows, all but the denser substances in their path outside. Metals, except thin layers of the lighter ones, oppose great resistance to them, and in sufficient thickness stop them entirely. They are absorbed to some extent by all matter, proportionally for any one substance to the thickness traversed.

Marx has recently shown that the velocity of X-rays through space is about the speed of light, giving a final conclusive proof that they are true ether waves.

RADIOGRAMS.—X-ray photographs or radiograms are, of course, really shadow pictures of opaque metals or bones, with varying photographic effect under the less dense portions of matter, such as the muscles and softer tissues of the body. A sort of counterfeit radiogram can be made by cutting out a tissue-paper hand, sticking thicker paper in the positions of the bones, and throwing its shadow from a strong light upon a wall or screen.

As well as their peculiarly penetrative powers, X-rays have the less pleasing property of causing terrible inflammation (X-ray dermatitis) in living tissues upon which they are directed strongly for some considerable time, resulting in death of the tissues as in frostbite or leprosy.

Another result of their energy has already been alluded to in the ionization of gases through which they pass. The gas molecules, suddenly and violently shaken by the passage of the ether pulses, are split up into their simpler parts, the electrons and the positive carriers. In high vacua these may remain free, but at ordinary pressures unite by their electric attractions with neutral atoms, forming the negatively or positively charged ions which under electric forces permit the passage of a current.

We have also noticed that ultra-violet light, *i.e.* a regular series of short waves, produces the same disturbing effect; heat, too, causing more violent vibration of the atom, may likewise disintegrate it.

CHAPTER XIV

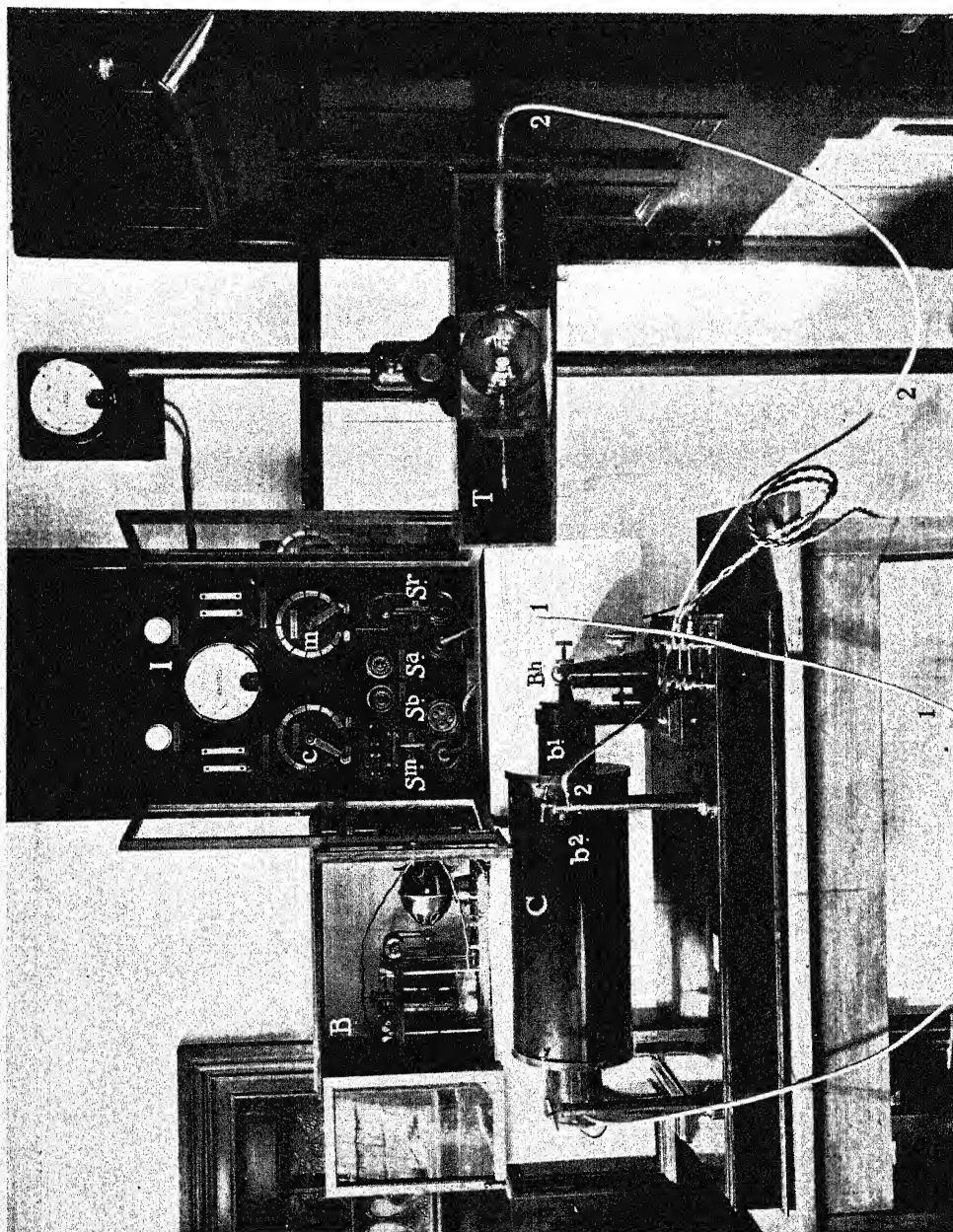
RADIOACTIVITY— α -, β -, AND γ -RAYS—PROPERTIES OF RADIUM—ELECTRON THEORY OF ELECTRICITY

MODIFICATION OF ATOMIC THEORY.—All this research upon electrons is very disquieting to faithful adherents of the older chemical theories that atoms are fundamental, indivisible units of substance, and the discovery of the phenomena of RADIOACTIVITY already discussed under their chemical aspects has finally broken down this narrower view of matter's smallest limits. To borrow a simile from the last-named subject itself, we may say that the older structure of theory was an unstable atom, and is breaking down (with the evolution of a certain amount of argumentative energy and heat) into simpler forms; but the analogy fails in this, that the material atoms finally remaining appear to be rather leaden and inert, while the new chemistry affords an active field of research and progress of which the very margins are as yet but dimly perceived.

RADIOACTIVITY.—Radioactivity, as already described under Chemistry, consists in the emission by certain heavy elements (radium, actinium, uranium, and the like), or by their compounds, of radiations of three forms (all three, however, do not always appear in one substance). These are: the α -RAYS, which prove to be positively charged particles, probably the positive carriers whose production in other circumstances we have described; the β -RAYS, negatively charged, and identical with cathode rays of abnormally high speeds; and the γ -RAYS, not material like the other two, but true radiations—in short, very penetrating X-rays. Their intensity is such that gases are ionized by the γ -radiation from about a one-thousandth part of an ounce of radium bromide after penetrating a mass of iron 1 ft. thick.

α -RAYS.—The properties of the first have been measured by the magnetic and electric deflection methods which we saw applied to cathode and canal rays, with the result that the α -rays prove to be of about the same mass as helium atoms, and to travel with about one-tenth of the speed of light. This small speed, coupled with their great mass, permits of their stoppage even by a sheet of paper.

β -RAYS.—The β particles, on the other hand, move really fast, and reach speeds up to 96 per cent of that of light itself in the fastest cases, though their velocities are far from uniform, the slowest only travelling



ARRANGEMENT OF APPARATUS FOR X-RAY WORK

at one-fifth of this rate. Nearly $\frac{1}{16}$ in. of lead is required to stop β -rays.

RADIUM CLOCK.—The difference between the absorptions of α - and β -rays is shown by Strutt's radium clock, which, as shown diagrammatically, consists of a thin glass tube R, containing radium bromide and supported by an insulating quartz rod Q. The glass is made conducting by a suitable paint, and is thick enough to absorb all the positively charged α -rays. The negative β - or cathode-ray particles, however, get through, and charge up the very light gold-foil leaves L, forming an electroscope. They diverge until they touch two metal plates inside the containing glass vessel V, are thus discharged and collapse, to begin their motion over again. The process goes on quite regularly, so we have a sort of self-winding clock. It is not everlasting, however, and as the radium spends its energy will gradually "run down", probably only going half as fast at the end of a thousand years or so.

ENERGY OF RADIUM.—The energy which drives the "clock" comes from the negatively charged β particles, showing most clearly that radium emits energy at a quite definite and appreciable rate. This is even more strikingly shown by the fact that pure radium salts keep themselves spontaneously at a temperature about $1\frac{1}{2}^{\circ}$ C. above surrounding objects. The heat is probably produced chiefly by the impacts of the α particles on the molecules of the surrounding air. A simple calculation shows that the heat energy thus thrown off by a pure radium salt would raise an equal weight of water from freezing to boiling-point in an hour.

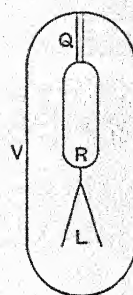


Fig. 132.—
Radium Clock

Other phenomena produced by radium and its congeners are PHOSPHORESCENCE or FLUORESCENCE in bodies susceptible in this way to X-rays, *e.g.* zinc sulphide and barium platinocyanide. All three kinds of radiation take a share in this result.

All radium salts are faintly luminous, and examination of the light shows it to be due to glowing nitrogen, so the explanation lies in the violent disturbance, like that in glowing vacuum tubes, set up in the air molecules by the radium's emitted energy.

Rutherford found by painful experience that radium compounds cause irritation of the skin, with deep-seated inflammation and sores difficult to heal.

The radiations produce fluorescence in the retina, so that a radium salt held near the eye causes a sensation of light even through the

eyelids, and in the cases of blind persons whose retinas and optic nerves are intact. To say that this gives hope of restoring sight to the blind is of course mere nonsense.

OTHER PROPERTIES OF RADIUM.—In addition to the radiations proper, the changes going on in radium are accompanied by the production of a heavy radioactive gas, the EMANATION, which in turn causes induced RADIOACTIVITY on substances with which it comes into contact, by depositing upon them a minute quantity of some further radioactive substance. Helium is also ultimately produced, and recent results, due to Sir William Ramsay, announce neon, argon, lithium, and sodium as products of the activities of radium.

All these changes show that we are dealing with an apparently SPONTANEOUS PRODUCTION OF ENERGY. In fact, if we could obtain 10 tons or so of pure radium, the heat energy alone, if convertible to useful work, would supply a power station of considerable size, and this not for an hour or a day but for probably two thousand years at least.

ORIGIN OF RADIOACTIVE ENERGY.—Whence comes this vast store of energy? Two conflicting theories have arisen, one that the source lies in radiations from external space, but no serious evidence in support of this view has come to light. The alternative hypothesis, that the energy is from within the atom of the radioactive substance itself, has met the facts squarely, and been capable of leading to prophetic deductions afterwards verified by experiment.

Direct evidence from this theory is afforded by the complete freedom of the effects from any variation under changed physical conditions. The rate of radiation is the same in the open air as in a thick leaden box, and the same again at the bottom of a mine half a mile deep. This is hardly possible if the energy is coming from external sources, unless the activity represents changes due to some past action.

Further, the effects of changed temperature on radioactivity is practically *nil*; strong heating (as long as the emanation is not allowed to escape) or cooling to the temperature of liquid air makes no difference in the rate of production of energy. A recent extreme test, that of enclosing radium salts in an extremely thick iron shell containing cordite, and exploding the cordite, must have exposed the radium to enormous pressure as well as to high temperature, and yet the only effect was a temporary gain in activity for a short time afterwards. Still, it must not be overlooked that in this case there was some effect, and an intra-atomic theory must include this among the facts it has to explain.

However this may be, the general independence of physical conditions

goes to show that mere molecular changes cannot give the key to radioactivity, for such great extremes of heat and cold profoundly alter ordinary chemical processes; the amount of the energy changes concerned also far transcends anything known in chemical reactions.

The theory that the atom is the seat of radioactivity is immediately supported by the known fact that the changes are always accompanied by the production of new substances, the emanation, the deposit causing induced activity, helium, lithium, and the other final products of the series.

Such decomposition would be expected in the more complex atoms rather than in the simpler atoms, and all the radioactive elements answer this condition, being of high atomic weights, 200 and upwards. Rutherford has done much to actually trace the stages in the disintegration of the radium atom, and latterly in the reverse process of the discovery of the parent atom from which radium itself springs.

COMPLEX NATURE OF THE ATOM.—The production of electrons in air ionized by light, X-rays, electric discharge, or other means (p. 55) has suggested a complex nature for the chemical atom and the possibility that every atom is made up of one or more electrons, with a compensating positively charged portion rendering it electrically neutral. Ionization consists in the tearing away of an electron, leaving the positively charged residue; the two oppositely charged portions may or may not seize upon uncharged atoms to form aggregates of greater bulk and mass.

EXPERIMENTS OF ELSTER AND GEITEL ON SOLIDS.—Solid bodies may likewise be made to yield up electrons. Elster and Geitel, in a brilliant series of experiments, have shown that a negatively charged, clean metallic surface is discharged by ordinary light—sunshine or an arc lamp, for example. A positively charged body is unaffected. The loss of negative charge is due to the emission of the electrons constituting the electrification; we must suppose that the energy drawn from the light waves is sufficient to loosen the attraction of the metal for these electrons, which then escape.

RAMSAY AND SPENCER'S EXPERIMENTS.—Still more striking, perhaps, is the result of Ramsay and Spencer's experiments on the effect of ultra-violet light upon an ordinary uncharged substance, confirming earlier work by Le Bon. To take the case of magnesium, they find that the metal emits negative corpuscles under the stimulus of these short waves; this is shown by the ionization produced in the gas surrounding the metal. The effect slowly decreases as time goes on, pointing to a kind of exhaustion of electrons from the surface layers of the metal; a few weeks' rest

restores the magnesium apparently to its original state, but the decay of emission is more rapid in the second experiment, still more so in a third, and so on. The phenomenon has been called photo-electric fatigue.

Further, some metals show breaks in the steady leak of electrons, pauses in the discharge before the emission is resumed, and the number of the periods of leakage thus marked off is equal to the valency of the metal. This seems to suggest that the magnesium atom, for example, loses an electron fairly easily, corresponding to one of its bonds of valency; the second less readily, representing the second bond. Thus chemical affinity would be due to the electrical forces of these electrons. The results as yet published are preliminary; after longer tests, the substances, it is to be presumed, will be chemically analysed with Sir William Ramsay's consummate skill. One awaits the result almost breathlessly; will the magnesium be magnesium still, or have we here a real laboratory transmutation of one element into another? A difficulty has been raised, that the fatigue set in when (as shown by the total amount of the leak) only a minute fraction of the surface atoms could have been split up. Perhaps, however, this small number represents atoms more unstable than the average; in this case the amount of new substance produced could never be great enough to be detected by ordinary chemical means.

ELECTRON THEORY OF ELECTRICITY.—The theory of the atomic constitution, so to speak, of electricity—the electron theory—affords simple explanations of ordinary electrical phenomena. All substances contain electrons as a part, and a separable part, of their atoms, and it is hardly to be supposed that all should hold these little corpuscles with equal firmness. Suppose that silk holds them more strongly than glass; rub the two together, bringing their surfaces into good contact, each wrenches some electrons from the other, but the glass rod yields more than it obtains. In other words, it is left with a deficit of electrons, or is positively charged, while the silk is negatively charged to the amount that it has gained in the rubbing.

The kinetic theory of matter prepares us to suppose that the corpuscles are not at rest, but are moving more or less freely in all directions through the atoms, attached now to one, now to another. In gases the exchange is difficult, because the molecules are so seldom within each other's range of action. Hence a gas only conducts electricity when it contains separated corpuscles, *i.e.* when it is ionized.

In an insulator, such as glass, the electrons must be firmly locked up in the atom, so that no carriers are provided which can move under an electric force. Such force can strain but cannot break the atom; the

strain is easily shown by passing polarized light through a transparent insulator which is under the influence of electric force, for instance, glass between the poles of a powerful electrical machine. Just such brushes and rings appear as are produced by mechanical strain (p. 29).

If the electric force is strong enough the atoms may be torn asunder, and a sudden rush of electricity takes place—an electric spark; the insulation is, in a happy phrase, said to “break down”. Gases at ordinary pressures may have their insulation thus broken down by a spark, and, unless they are ionized, this is the only way in which they allow the passage of electricity.

CHAPTER XV

ELECTROLYSIS—ELECTROPLATING AND ELECTROTYPING—BATTERIES—ACCUMU- LATORS—NATURE OF MAGNETISM

Some liquids are insulators—paraffin oil, carbon bisulphide, and the like. Others, however, conduct electricity in a special way, known as ELECTROLYSIS, reacting chemically to the electric forces. Such liquids, called ELECTROLYTES, must be compounds, and water and solutions of salts in water are typical electrolytes.

The dissociation theory of solution tells us that the molecules of a salt, *e.g.* of common salt (NaCl), dissolved in water, are in a constant state of exchange, the sodium (Na) atoms roaming free during the greater part of their existence, and the rest of the molecule, the chlorine (Cl), also free and separate from the sodium. The sodium atom is not neutral, but is positively electrified by the loss of an electron, and in this state is an ion. The chlorine atom is negatively charged to an equal amount by the electron missing from the sodium. This is shown by the fact that under electric force, applied by metal electrodes dipping into the solution, two opposite streams of matter begin to flow, sodium travelling to the negative plate, the cathode, and chlorine to the anode. This sort of chemical analysis is what we mean by ELECTROLYSIS.

The amount of an ion brought to an electrode is proportional to its chemical equivalent; the amount is also proportional to the quantity of electricity which has passed. Combining these two experimental facts, we reach the simple result that the same number of atoms of a monad element is always brought to an electrode by the same quantity

of electricity, whatever the element may be; half as many of a diad element, and so forth. In other words, a monad atom always carries the same charge, a diad twice that charge. To take a definite instance: 1 grm. of copper in electrolysis is always associated with a positive charge which is equivalent to that of 2.7×10^{22} electrons, a vast throng, it is true; but 1 grm. of copper contains about 1.3×10^{22} atoms, roughly half the first number, so that with each atom is associated a positive charge, just that which would be left after the loss of two electrons. Thus each atom of divalent copper has lost two electrons. Any other element leads to similar results; monad sodium loses one electron per atom, triad aluminium three, monad chlorine gains one, and so forth.

In an ordinary solution, therefore, as in a gas, ionization or dissociation must again precede conduction. The ions of the dissolved salt are in very much the same case as those of a gas, and consist of positively and of negatively charged carriers. In the liquid these are the atoms, plus one or more electrons for the negative ions, robbed of one or more in the case of the positive. Their speeds are far slower than the gas velocities, as we might expect from their constant encounters with the molecules of the solvent liquid. The motion can be directly watched in the cases of some coloured ions by the steady change of tint which spreads from electrode to electrode. The different elements prove to have very different ionic speeds. Electrolysis sometimes results in marked differences in concentration, and therefore of colour in different parts of the solution. Thus in the electrolysis of a solution of copper sulphate the blue colour near the cathode gradually grows paler as copper deposits there from the solution. Near the anode, if this is made of copper, the concentration increases as more copper passes into solution, so the colour darkens; the total quantity of the salt in the whole solution remains unchanged.

Besides the use of electrolysis in chemistry and metallurgy electroplating and electrotyping are its two most important applications.

ELECTROPLATING AND ELECTROTYPING.—The processes are essentially the same, viz. the deposition of a layer of metal from solution upon the cathode, which is the object to be plated, or a cast of the block to be typed.

Thus in **SILVERPLATING** the current is led through a bath of potassium silver cyanide from a silver anode. The cathode, the spoons or what not, to be plated, is of inferior metal, such as nickel, clean, and with a smooth surface. The action is somewhat complicated, potassium being the ion to appear naturally at this cathode under the electric action. However potassium cannot thus be formed in the free state in the presence of water

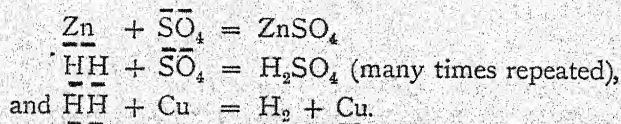
so a secondary chemical action sets in, resulting in the formation of potassium cyanide in the solution and the deposition of silver on the spoons. The action goes on best when the liquid is hot, and there is also a best value for the current density to secure the most uniform plating. By CURRENT DENSITY is meant the strength of the current per square inch of metal surface. The deposit has finally to be burnished, and in some modern plant this polishing is effected during the plating; a more even and dense deposit is thus obtained.

In ELECTROTYPING, an impression of the wood block is taken in wax, which is then rendered conducting by a thin layer of black lead or graphite. Thus treated, it forms the cathode of a bath of copper salts, and upon it is formed a thick copper deposit, which naturally is an exact copy of the original block. The wax is removed and the copper backed up by a rigid support; it is then, after any necessary retouching, ready for printing.

ELECTRIC CELL OR BATTERY.—The ordinary electric cell or battery shows a sort of reversal of electrolysis. Instead of the flow of electrons due to electric forces causing chemical changes, the chemical energy is the starting-point, and produces electrical force which through suitable conductors can supply a flow of electricity.

SIMPLE CELL.—The simplest possible form of cell—two plates, one of copper and the other of zinc, both dipping into a vessel of dilute sulphuric acid (H_2SO_4)—will explain the essentials of the action of all.

Zinc can dissolve in the acid, but in doing so each atom of the metal loses two electrons (it is divalent) and combines with the SO_4 part of an acid molecule by means of the two electrons of the SO_4 . The displaced two ions of hydrogen, the H_2 part, short of two electrons, seize upon the SO_4 of the next acid molecule, and so the action proceeds until finally the last H_2 , the ions of an acid molecule close to the copper, seize two electrons from a copper atom, becoming a complete molecule of hydrogen, which is thus evolved in the gaseous state at the copper plate. If minus signs (—) drawn over the top of the chemical symbols express negative ions, *i.e.* atoms with excess of electrons, while positive ions, *i.e.* those with defect of electrons, have the sign placed below, we can represent the action by a series of chemical formulæ:—



The copper plate is thus seen to be left with a deficit of electrons, and

if joined by a conducting wire to the zinc an equalizing action will go on by which the excess of electrons left from the ions of zinc which went into solution passes along the wire to the copper. The method of this equalization in the metals we shall see later, but its obvious effect is a displacement of electrons from zinc, through the wire, to copper; in other words, an electric current (as we ordinarily define it as the flow of *positive* electrification) from copper to zinc.

It is beginning to be apparent that the old allotment of the names positive and negative was unfortunate, since the negative is so frequently the moving agent in flows of electricity.

DECKER CELL.—A form of primary battery which promises to become of some practical importance is the Decker cell. It is a so-called bichromate cell, the liquids consisting of dilute sulphuric acid into which a zinc plate dips, and a strong solution of sodium bichromate containing the positive plate, of graphite, with a corrugated surface. The zinc and its acid are held in a very thin-walled flat porous pot; many special devices give greater strength for a given weight, ease in running the liquids in and out, and so forth. Such a cell, with five or six plates, weighing 17 lb. in all, will give a current of 24 amp. for six hours at a pressure of about 1.7 volt, supplying about $\frac{1}{4}$ of a Board of Trade unit of work. Weight for weight, the output is three or four times that of a storage cell; the Decker, too, depreciates less rapidly, is more quickly and easily recharged, and can be run down to no voltage, whereas a storage cell is much injured by excessive discharge. The cost of materials, however, is at present high.

The STORAGE CELL or ACCUMULATOR derives its chemical energy from an electric current during charging, and in the discharge reconverts that energy into the electrical form again—of course at a loss. What happens at charging is that the water of the dilute acid in the cells is electrolyzed and split up into its two gases, hydrogen and oxygen. These are absorbed by the spongy surface of the lead plates, made as large as possible by a grid formation. The hydrogen ions, positively charged by the loss of electrons, go down stream to the cathode; the oxygen ions, with excess of electrons, come to the anode, the "red plates" of the cell. It is chemical energy that is thus stored, and the discharge consists in the reversal of the process by the recombination of the absorbed gases.

DIFFICULTIES IN USE OF ACCUMULATORS.—Practical types of accumulator differ a great deal in the shapes of grids and in the chemicals with which the grid meshes are sometimes packed to facilitate the actions of charging. Perhaps the three greatest difficulties in the use of accumulators are their great weight, their liability to spilling, and the fact that

they cannot be discharged beyond a certain point without serious damage to the cell.

Attempts to replace lead by lighter substances have been comparative failures, nothing appearing to combine the necessary strength with great absorbing power for the gases like a lead grid.

An ACID JELLY has been used to do away with risk of spilling, and is found to permit the chemical action to proceed freely.

SOLIDS AS CONDUCTORS.—The electric current, as we have often mentioned, and as everyday experience shows, flows readily enough in such solid conductors as copper wires, and here the passage of the electrons

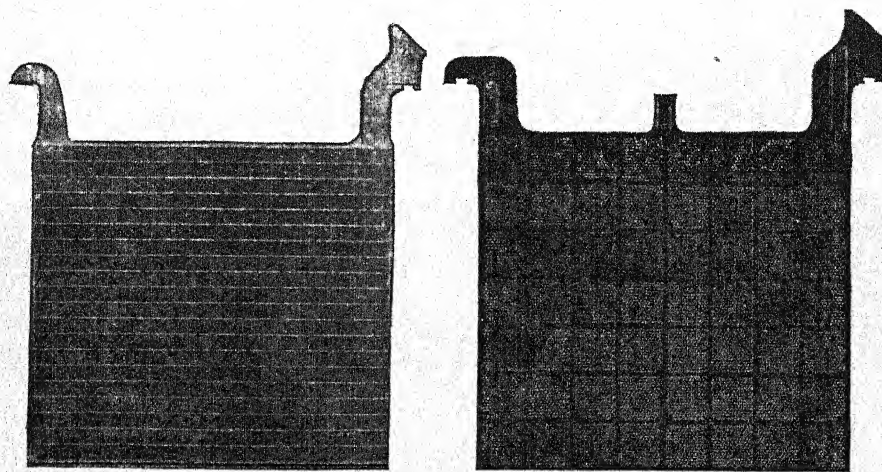


Fig. 133.—Accumulator Plates

must be a very different process to that going on in conducting liquids or gases. The atoms of copper are so closely packed that no great free motion is possible. However, the small size of the electron still permits it to wander at will within its atom, and the close atomic packing allows it to leap easily from one atom into the next. The time during which it is free must be small compared with that during which it is enclosed in an atom, in all probability only about one five-thousandth part of its existence.

In copper which is not carrying a current, then, the electrons are constantly changing their prisons, but as equal numbers move on the average in every direction there is no motion of electricity in any one particular line. But now apply electric force by means of a battery joined to the wire, and the atoms become polarized; that is, there is a tendency for each negative electron to come to that side of its imprisoning atom which is nearest the positive pole of the battery. So the escape of an electron into

the next atom is guided, and takes the same direction throughout the wire—the electrons travel slowly along it towards the positive end; in other words, a current flows in the wire. With the ordinary convention as to positive flow, this current is from the positive pole to the negative, through the wire. The actual flow is thus that of the negative electrons, the larger and clumsier positive carriers taking no appreciable part in the motion. Fresh electrons are supplied from the zinc negative pole of the battery.

PRODUCTION OF HEAT.—The jostling of the corpuscles in darting from atom to atom, stopped by each in turn, wastes some of their energy of motion as heat, which, as we have seen, is always a characteristic of the electric current.

Another effect is the **PRODUCTION OF MAGNETIC FORCE**, which is thus a result of the motion of electrons. Remembering that the so-called

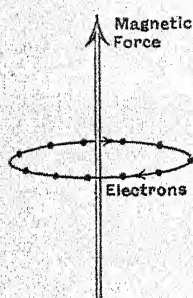


Fig. 134.—Electrons and Magnetism

“direction of current” is opposite to that of the moving electrons, we see that the end of a current-bearing spiral at which the electrons seem to move clockwise is the north-pole end. Or, if we reduce the coil to a flat single ring in which the electrons revolve, we can connect the direction of magnetic force with that of the electron’s motion as shown in fig. 134.

NATURE OF MAGNETISM.—Such motion of electrons produces magnetic force, and there is no reason to suppose that any other action can bring about the same result. In other words, the magnetism of an ordinary permanent steel magnet should be due to moving electrons. Each molecule of the iron must contain or be girdled by a ring of electrons rotating like a moving equator about it, or perhaps carried round with the molecule in some rotation of its own. Such an explanation in terms of molecules is demanded by the known facts of magnetism. It is impossible to separate the north pole of a magnet from a south pole; however many times we break it, each piece still possesses its two poles, and is a complete magnet. The new poles which appear at the broken surfaces cannot have been created by breaking; they must have existed already in the mass of the steel, so closely applied to each other that the north polarity of one neutralized the south of the other, so far as any external effect is concerned. So we are led to see a magnet as a host of little magnets, their poles all pointing in the same direction as those of the whole bar, packed closely together throughout the steel. These little magnets must be the molecules themselves, for if they were anything greater, anything divisible by mechanical means, breaking a magnet must sometimes snap them

asunder, and so leave the two half-magnets, one with two north poles, the other with two south poles—and this has never occurred.

EWING'S EXPERIMENT IN MAGNETS.—The magnetization of iron and steel shows many peculiarities which, as Professor Ewing has been able to show, follow at once from this fact, that each molecule is in itself a tiny magnet with its own north and south poles. In an "unmagnetized" piece of the metal it must be supposed that the little magnets face all ways indiscriminately, so that they produce no external effect. This Ewing illustrates by a large number of little compass needles, representing the molecules, at equal distances apart; he finds that they tend to set in little chains, the north pole of one attracting the south pole of another, the number of magnets in a chain varying greatly.

If a magnetic force is applied to iron it becomes a magnet; as the applied force is steadily increased the strength of the magnet increases also, at first slowly, afterwards more rapidly, then more slowly again, till at last it reaches a maximum amount, when increasing the force produces no further effect. All this the model illustrates; a small magnetic force causes some of the weakest chains to break up, their constituent "molecules" facing round to point in the line of the force. As the latter is increased, more and more chains break up, till nearly all the needles point the same way. After this the few remaining combinations require great force to unlink them; and at last, when all are broken, no further effect is possible, however great the force becomes.

When magnetizing force is removed iron does not lose all its magnetism, and this is represented in the model by the fact that the needles do not then all return to their old chain formation, but many remain pointing still in the direction taken up under the force.

STEEL.—Its hardness shows that steel must have its molecules so arranged that they are more difficult to move than those of soft iron; this would lead us to expect it to be less readily magnetized than iron, but more permanently retentive of the magnetism it gained. And this is exactly true; iron is far better than steel for electromagnets when mere susceptibility to magnetic influence is required; but we must use steel for permanent magnets. This also the model illustrates, for a more closely set group of needles is less easily disturbed than those of more open spacing, but keeps the straight-line formation better when the force is gone.

ELECTROMAGNETIC FORCES.—The magnetic forces of two currents are readily shown in flexible conductors. If we pass fairly strong currents through two such movable conductors as long hanging loops of tinsel strip, the two move so as to set themselves as nearly as possible

parallel and close together. If we bring together and parallel two strips in which the currents are in opposite directions, they repel each other; it is only between two parallel streams of electrons moving in the same direction that attraction takes place. These ELECTROMAGNETIC FORCES, as they are called, far outweigh and conceal the repulsions natural to the electrons themselves in the two currents.

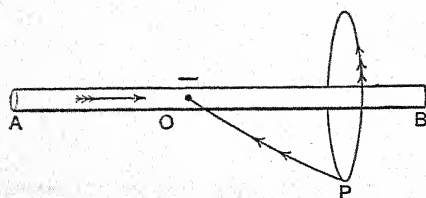


Fig. 135.—Field of Force of Electron

PO in the direction of the double arrow. There is also the magnetic force due to O's motion, at right angles to the motion and also at right angles to OP, in other words, acting in such a direction as that of the circle marked with a triple arrow. So the line AB of the motion of O is ringed about with circles of magnetic force, and the space about O is traversed by straight lines of electric force ending on the electron at O.

These two sets of LINES OF FORCE fill the space around any conductor carrying a current, but as soon as the current ceases, *i.e.* the electrons are stopped, the magnetic lines die away. The ordinary electric lines are in general neutralized, because, in addition to the moving electrons, there are the stationary positive parts of the atom, and these also produce electric force acting *from* themselves, *i.e.* giving lines similar to those of the diagram, but with the double arrows reversed. Their magnetic forces are *nil*, since they are not in motion.

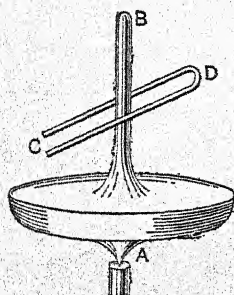


Fig. 136.—Model of Electromagnetism

In all cases the electric lines move through the ether with the moving charges, but the magnetic lines which are produced when motion begins spread out from the wire in ever-widening circles, sending an electromagnetic disturbance through the ether. The speed of the spreading of these rings, as we shall shortly see, is the speed of light.

VORTEX ACTION.—In speaking of the ether some sort of vortex or spinning-top motion was suggested as existing in it; it is interesting to find that some similar idea may explain the magnetic effect of the motion of an electron. Take the case of the top of fig. 136 spinning about the

axis AB; slip over its spindle a wire CD, bent as shown. Then the point A may represent an electron, the end B of the spindle a magnetic pole, and the whirling body of the top the ether which permits interaction between the electron and the pole. As long as the point A remains at rest, B also is unmoved; but pull the support of the top, and therefore the "electron" A, sharply a small distance to one side perpendicularly to the slot; then the "pole" B moves not in the same direction but parallel to the line CD, *i.e.* at right angles both to the line AB and to the motion of A, just as in the actual electromagnetic phenomenon.

CHAPTER XVI

INDUCED CURRENTS—INDUCTION COILS— CONDENSERS—TRANSFORMERS—ELECTRON THEORIES OF HEAT AND LIGHT

TRANSITION PERIODS OF ELECTRONS.—So far we have only considered the electron at rest or in a state of uniform steady motion; but what of the transition periods, when it is "getting up speed" under the action of electric force, or slowing down to rest after that force is removed. The movement of the electron carrying its magnetic and electric fields with it through the ether represents a certain amount of energy derived from the propelling force, the energy of the electric current in which the electron flows. Energy is indestructible; where then does this energy go as the electron stops, and whence does it come when the electron is being accelerated?

A return to the case of ordinary matter may help us. If we only knew matter at rest we could never by ordinary methods know anything of its mass, which, directly or indirectly, is measured by its ability to generate or to change motion. If we allow a body to fall it acquires energy in proportion to its mass and to the square of its speed. If we weigh a body to determine its mass, we are really comparing its weight with that of another, *i.e.* comparing the forces which would produce motion if we allowed the two to fall.

Even if a body were moving but never changed its speed, its mass would not concern us, for it could never exercise force or pressure; we might watch its motion, but if we could not interfere with it the science of mechanics would be unknown. Mass or inertia, then, makes itself

manifest when a body is undergoing acceleration or retardation of its motion; inertia has been defined as the property by which a body resists change from rest or steady motion in a straight line. Has electricity in motion, then, any property akin to inertia, in virtue of which it needs force and *the expenditure of energy* to produce or change its motion? If an electric force takes an appreciable time to bring electrons to their full speed, *i.e.* to establish a steady current, and if that current persists for any time after the force is gone, then electricity has such inertia.

INDUCED CURRENTS.—Faraday first showed such phenomena as these. If two coils are laid side by side, then the starting of a current in one produced a momentary reverse current in the other, a backward jerk of electricity, so to speak. When the first current stops there is a momentary forward current in the second coil. The same effect is produced by plunging a magnet into a coil or removing one from it; it is thus the magnetic force of one current, in the first experiment, that sets up the **INDUCED CURRENTS**, as they are called, in the second coil. If one coil alone is used, and a current is started in it, the reverse induced current sets in and delays the rise of the true current to its full value by a brief but measurable instant of time, and at the stoppage of the current the induced current continues and delays the complete cessation of flow.

Here, then, is a true inertia, which shows where the missing energy above referred to has gone. It has passed out and been utilized in the production of the electromagnetic force about the current, and has flowed back through it when the force is destroyed. In its production and in its decay it generates electric forces capable of causing temporary motion of electrons in opposite directions in the two cases, giving, as it were, momentary pushes as it passes to its steady state.

INDUCTION COIL.—Whenever a variable magnetic force plays through the turns of a coil of wire these induced currents appear in the coil, flowing most strongly while the force is changing most rapidly, not flowing at all when the force is, even for a moment, steady. The **INDUCTION COIL** makes use of the fact; two separate coils are wound about an iron core composed of a bundle of iron wires. In one coil a current flows intermittently from an ordinary battery of a few cells. The breaks of current are brought about by an electromagnet (the iron core) by exactly the same action as that of the hammer in an electric bell. Thus when the current starts, the core is magnetized, and its magnetic force naturally acts through the second coil. In each turn of this, therefore, electric forces arise, and, if the number of turns is very great, the forces may be strong enough to drive an electric current across an air gap, even

one some inches long, in the form of sparks. In large modern coils, such as the one shown, the make and break is effected by the aid of a motor.

MAKE AND BREAK.—This induced or secondary current ceases to flow

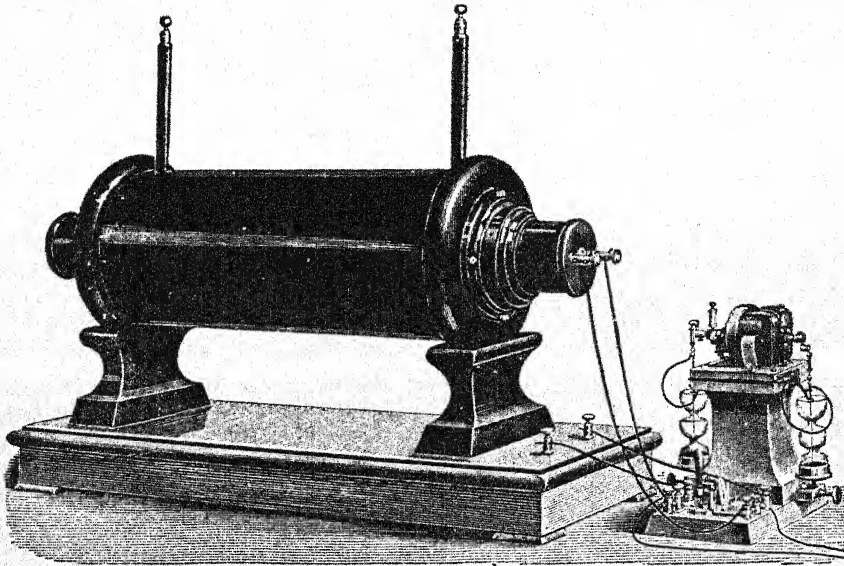


Fig. 137.—Induction Coil

as soon as the first or primary current has become steadily established, but an instant later comes the “break” of the primary, and again an induced current appears in the secondary, this time in the direction opposite to that it previously took. So the process continues: high-pressure but momentary flows of electricity rushing to and fro in the secondary coil and spark gap. The spark is first in one direction, then in the other, alternately.

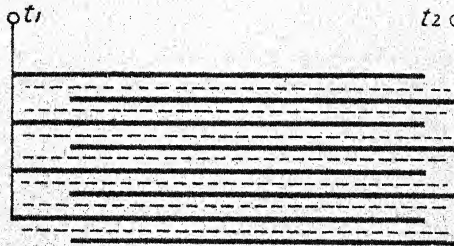


Fig. 138.—Condenser

CONDENSER.—With coils of any considerable size the action is modified by the use of a condenser; this consists of two equal sets of tinfoil sheets separated and insulated from each other by interleaved mica, as in the figure. The two sets of sheets are connected one to each side of the make-and-break apparatus of the primary circuit, so that, instead of sparking across the

little gap at the vibrating hammer, electricity can flow into and charge the condenser, electrifying one set of sheets positively and the other negatively. At "break" this is just what occurs; without the condenser a little spark, due to the induction of the primary upon its own turns, prolongs the flow of the current and makes its cessation less sudden. With the condenser the electricity finds the easier path into the sheet of tinfoil, and "break" is more abrupt and the secondary currents more powerful. But the electricity which has stored itself in the condenser surges out again, and, with tinfoil sheets of the right size and number, this outflow can be made to occur just as the primary circuit is remade by the vibrator's next swing. It opposes the ordinary current, and so renders "make" more gradual. Hence the secondary effect at make is only trivial.

In this way the sparks in the secondary circuit can be enormously lengthened and strengthened, but they are now practically all one way; those which, without the condenser, would be produced at "make", are almost entirely suppressed.

The ALTERNATING-CURRENT TRANSFORMER is very similar in theory. The fluctuating magnetic field of the primary is produced, not by a battery and a make-and-break interrupting device, but simply by passing an alternating current. This is one which, surging to and fro in a conductor, rises to full strength in one direction, gradually dies away, rises to full strength in the opposite direction, then dies away again, and all this some fifty times per second. Thus the varying current causes a varying magnetic field, which, again, induces a varying secondary current, another alternating current in fact, flowing under an electrical pressure or voltage, which is to that in the primary as the number of windings in its coil are to those in the primary. If the secondary windings are 100 times as many as the primary, we "transform up", say from 500 to 50,000 volts; if, on the other hand, the primary turns are 100 times as many as the secondary, then we "transform down", as by interchanging the voltages quoted.

ELECTRICAL MASS.—The electron then requires energy to start its motion, to change its motion, or to stop its motion, and thus has what in matter we should call a mass. This apparent or pseudo mass is purely due to its charge, and is over and above its mass as ordinary matter. We will call it the ELECTRICAL MASS of the moving charge.

AMOUNT OF ELECTRICAL MASS.—An exact mathematical calculation of its amount shows that it is proportional to the square of the charge, and that it depends in a very complicated way upon the speed of the electron. For ordinary velocities, or even up to perhaps one-tenth of the speed of

light, it is a practically constant quantity, but as its speed increases it becomes greater more and more rapidly as it nears the velocity of light itself. The physical reason for the changed electrical mass may be put simply in this way: the electron O (fig. 139) moves along AB , its electric force at P is along PO and its magnetic force through P perpendicular to the paper. The electron moves through this magnetic field and so generates "induced" electric forces. These are perpendicular both to the motion of O and to the magnetic force at P , *i.e.* they act along the line PM . So there are now two electric forces at P , and the total must be along some direction between the two, say along PQ . The greater the speed the greater is the force along PM , and so the more PQ differs in direction from PO . That is to say, at very high speeds the electric force is more nearly perpendicular to the line of motion AB , and so generates a stronger magnetic force. Thus the retarding force is increased, in other words the effective electrical mass has become larger.

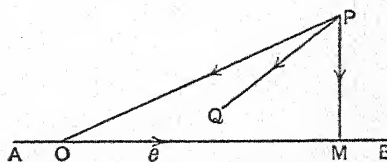


Fig. 139.—Electrical Mass

KAUFMANN'S EXPERIMENTS.—Mathematics enables us to calculate the electrical mass for various speeds as compared with that for slow speeds. The results are given in the second column of the following table from the mean of two slightly different calculations, for speeds of various percentages of that of light.

Per Cent of Light's Speed.				
96	.. ..	2.85	.....	2.70
88	.....	1.86	.....	1.96
81	.....	1.50	.....	1.61
75	.....	1.40	.....	1.48

Kaufmann, by experiments similar to those described for cathode rays, measured the masses of the negatively charged β radiations of radium, which fly with speeds near that of light, and found that their total mass did increase with increasing speed. Now follows an extraordinary deduction: if only a small proportion of this total is electrical this total will not be much greater than for slow-speed particles, but if all the mass were electrical the results should agree with those of column 2. Column 3 shows Kaufmann's results, proving within the limits of experimental error in so difficult an experiment that the whole mass of an electron is electrical. We have to deal not with a charged particle of ordinary MATTER, "whatever unknown entity is hidden by that familiar phrase", as Sir Oliver Lodge pointedly says, but with ELECTRICITY, as it were disembodied.

We have not proved that the whole positive carrier is made up of electricity, so the atom is left as a small particle of matter, associated in some way with a positive charge accompanied by one or more neutralizing corpuscles of negative electricity, its electrons.

Larmor and the mathematical school hold it as certain that positive electricity must exactly resemble negative with reversed properties, a true "plus" for the electron's "minus", but as yet the positive electron, if such there be, has eluded its pursuers and only presents its charge accompanied by masses as large as hydrogen atoms. Recent rumours of the discovery of a positive electron smaller even than the negative remain as yet unconfirmed. It is to be noted, however, that Professor R. W. Wood has recently announced that in optical experiments on sodium vapour certain phenomena occur depending on the rotatory motions of electrons in magnetic field, and that in addition to the usual effects indicating negative electrons he has observed reverse effects suggesting that similar separate positive parts exist in the sodium atom.

ELECTRONS AND HEAT.—The electron, far-reaching as its effects are in the electrical properties of matter, might well be expected to play some part in other branches of physics.

In heat we saw it as the agent in conduction, distributing energy throughout the bulk of a solid, and affording us the explanation of the simple connection between good conductivities for heat and for electricity.

In its directed motion it produces the electric current; in its acceleration it throws out energy through the ether. Now this energy resulting from the electron's change of motion will be radiated if the change is one of direction as well as if it is a change in the actual speed. For to alter the course of a moving body having inertia requires the employment of force and the expenditure of energy.

ELECTRONS AND LIGHT.—An electron whirling about its atom is in such case: the bulk of the atom does work upon it in keeping it in its orbit, and this work is spent not in heat but in electromagnetic radiation. The motion of the electron relative to any point in space is constantly changing, the magnetic forces at the point are thus also variable, now a maximum, now zero, then a maximum in the reverse direction, then zero again, returning to its previous value at the end of each spin of the electron. In other words, periodic disturbances continually pass the point with the characteristic ether speed, that of light. These make up true electromagnetic waves propagated from the radiating atom, and the frequency depends only on the speed of rotation of the electron, *i.e.* the number of times it describes its orbit per second. If that number lies

between 400 and 700 billion per second the waves will have the necessary frequency to stimulate the retina and optic nerves—we have light waves. A little slower and we have infra-red or heat waves, a little quicker ultra-violet. Light waves then are electromagnetic in character: small wonder that they play a conspicuous part in so many electrical phenomena, such as the discharge of negatively electrified bodies by sunlight.

WORK OF LORENTZ AND ZEEMAN ON ELECTROMAGNETIC THEORY OF LIGHT.—The labours of Lorentz on the mathematical side and of Zeeman in experimental verifications have put the electromagnetic theory of radiation, that is the emission of light and other ether waves, upon a sure basis. Zeeman in 1896 discovered direct experimental evidence of the activities of the electrons in an ordinary luminous flame.

He tested the action of a powerful electromagnet upon a flame containing a metallic vapour, *e.g.* an ordinary Bunsen burner tinted yellow by a bead of a sodium salt.

The bright lines of the spectrum are perceptibly broadened when the magnet is switched on, and if the magnetic force is strong enough it breaks each line up into two or three or even more similar lines.

Taking the simplest case, a bright line breaks up into two when the flame is viewed in the direction of the magnetic force through a hole drilled in one magnet pole. One of the new lines is a little lower down the spectrum, *i.e.* nearer the red end, and the other somewhat higher up than the original line, showing an apparent slowing of half of the waves and quickening of the other half. This, as Lorentz at once perceived, is explained if the radiation is due to small moving electrified particles in an atom, which whirl round and round in their prison. The reaction upon these particles is shown in the figure (fig. 140), in which the magnetic force is supposed to act downwards into the paper. Mechanical force is produced by the magnet in a direction perpendicular both to its magnetic action and to the motion of the electrons, so that in the diagrams it is radial, towards the centre in *a*, from it in *b*, according to the direction of spin. So in case *a* there is an increased pull to the centre, and the particle has to quicken up in order to increase its centrifugal force enough to keep its distance; in *b*, on the other hand, the lessened pull causes a slowing of the revolving electron. Hence the light is broken up into two beams, one of quickened and the other of retarded waves.

If the flame is examined at right angles to the direction of the magnetic force the vibrations we have again considered appear once more: but in addition there are vibrations perpendicular to the line of view (and therefore producing light) which are in the direction of the magnetic force. These

remain unaffected, because, as explained for the other case, the mechanical force is produced when the magnetic force is at right angles to the motion of the electron. Thus viewed in this way a bright line remains, and the two new ones spring up on either side of it.

Exact measurement enables us to deduce the charge of the revolving carriers and the kind of charge. It proves to be negative and equal to the usual electron quantity, 3.4×10^{-10} units, convincing proof of the identity of the particles which cause light with those concerned in the electrical discharge of vacuum tubes.

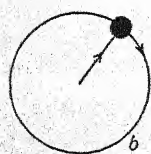
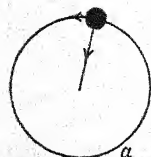


Fig. 140.—Zeeman Effect

The Zeeman effect, it will be seen, consists of a change in the number of vibrations per second of the electrons in a flame and so in the wave length emitted; this gives a simple way of showing the action. Place a bright-yellow sodium-tinted flame between the poles of an electromagnet, which is not, however, to be switched on at first. At some distance away put a small feebler sodium flame. This, owing to resonant absorption, appears dark on the bright background of the other flame. On strongly exciting the magnet the Zeeman effect alters the wave length of the light of the first flame, which is therefore no longer absorbed by the second smaller one. The latter therefore appears to become brighter.

CHAPTER XVII

HERTZIAN WAVES—WIRELESS TELEGRAPHY AND WIRELESS TELEPHONY

HERTZIAN WAVES.—Electromagnetic waves, in every way similar to those of light except that they are vastly longer, say from an inch up to many yards instead of two or three millionths of an inch, can be produced, detected, and exactly measured in the laboratory by purely electrical means, as was first shown by Hertz in 1889.

Suppose we have a long wire in which electrons move, not steadily in one direction but to and fro like the bob of a pendulum. They set up a magnetic field which is not uniform, but fluctuates from a maximum in one direction to an equal maximum in the other. Thus alternately opposite pulses of magnetic force are sent out through the ether, and waves of electromagnetic energy radiate from the wire.

In the apparatus shown two spheres A and B are alternately charged positively and negatively by the electrical surgings set up by the discharge of the induction coil C, fig. 136 (connected by wires to the oscillator as shown), across the spark gap between the small balls. Suppose at a given instant A is the negative sphere, electrons dart from it to B in a sudden rush and overcharge B, leaving it negative and A positive (an instance of the effect of their inertia). The electrons on B now swarm back, and repeat the process at a rate, for a large coil, of some millions of times per second. Each "vibration" of the charges sends out an electromagnetic pulse, so that waves of frequency several millions per second are spread through the ether. Suppose there are 10,000,000 per second, travelling as ether waves with the usual light speed of 186,000 miles per second, they move $(186,000 \div 10,000,000)$ miles in the time of each vibration, in other words their wave length is this quantity about 33 yd., vastly longer than for light.

If we can measure this wave length directly, then knowing the frequency of the vibrations we can calculate back to the speed with which the waves travel, and this has been done by several methods, all giving the expected 186,000 miles per second.

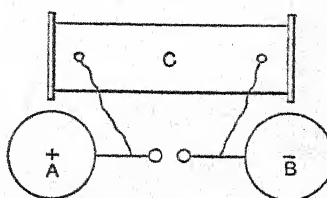


Fig. 141.—Hertzian Oscillator

These long electromagnetic waves are those utilized in WAVE or WIRELESS TELEGRAPHY. Hertz, and more recently Righi, Bose, and others, have proved that the waves can be reflected by flat or curved metal mirrors, refracted by pitch prisms or glass lenses, caused to interfere and to produce diffraction effects exactly as do light waves. They are naturally polarized, like a plane-polarized light beam, because the direction of their vibrations is necessarily fixed by the spark gap and spheres which produce them. A wire grid with the line of wires parallel to the direction of vibration refuses to let the waves pass through, because the grid is a conductor in the direction of the electrical disturbance. But if the wires are perpendicular to the vibrations, the waves pass through; the grid thus resembles the piles of plates used for analysing polarized light.

Wave signalling between an oscillator producing the waves and a detector to signal their arrival was long a laboratory experiment before becoming a practical commercial means of telegraphy.

The HERTZIAN DETECTOR was a ring of wire, nearly complete, but with a small spark gap; by suitably choosing the size of this, it could be made to "resound" electrically to the surgings set up in it by the impact of the waves. In other words, the motion of the electrons to and

fro around the ring may, for the correct size, take exactly the same time as that between successive waves; thus each wave emphasizes the effect of the last, until the electrons move in the ring with sufficient violence to leap the air gap as a tiny spark. The principle is once again that of resonance, like the tuning fork answering to appropriate sound waves; in the present case we have ELECTRICAL RESONANCE.

THE COHERER.—The real beginning of Hertz-wave telegraphy dates from the discovery of the COHERER, which in its simplest form consists

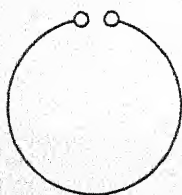


Fig. 142.—Hertzian Detector

merely of a glass tube containing metal filings, into which are placed two metal terminals which can be connected to a circuit made up of a battery and an electric bell. The remarkable property of this tube is that the filings, lying loosely in contact and offering very great resistance to the passage of a current, suddenly become quite good conductors when the electric waves fall upon them. The filings appear to adhere together, or, as

Lodge termed it, to "cohere". The fall in resistance is not slight; a coherer, through which only a tiny current originally passes, will, after receiving radiations, allow sufficient to ring the electric bell. A slight shake or tap instantly restores the tube to its first badly conducting state.

RECEIVER.—Such a coherer circuit then can be arranged to record the advent of electric waves, which set the bell ringing; the vibrations of the latter may be arranged to shake back the filings ready for another signal. But a better arrangement is to replace the bell by a relay which closes a second circuit containing ordinary telegraphic recording apparatus. The

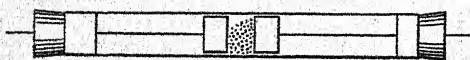


Fig. 143.—Coherer

waves set the current flowing in the first circuit, the relay operates, and so produces a telegraphic signal.

MARCONI'S SYSTEM.—Lodge, using a coherer of this type, signalled over some 50 yd.; but, as he himself says, he did not see the particular practical advantage of thus telegraphing with difficulty instead of with ease by the highly developed telegraphic methods which make use of a conducting wire. Accordingly it was left to Marconi, a pupil of Righi, of Bologna, to develop the practical side of the matter. He improved the coherer, and, having obtained the support of the English Post Office, conducted large-scale experiments which have resulted, as everybody knows, in moderately certain wireless communication across the Atlantic between Great Britain and New York, and the constant possibility of keeping in touch with liners in mid ocean.

MARCONI PLATES AND RIGHI OSCILLATOR.—In an improved form of apparatus Marconi used two large plates of metal separated by spark gaps, the one from the positive pole, the other from the negative of a powerful induction coil. The two plates are connected through a RIGHI OSCILLATOR, which is an improvement upon one used by Lodge, and consists of a flat cylindrical vessel filled with highly insulating oil. The top and bottom are circular ebonite plates, with a small brass sphere fixed at the middle of each, shown at X and Y. The sides f, f are flexible, and so permit slight adjustment of the length of the small oil gap between the spheres X and Y. The system operates by sparks across the air gaps between the poles of the induction coil and knobs on the large plates, which then discharge across the oil gap in the middle; the final spark is highly oscillatory, sending out a great number of waves.

The RECEIVER consists of a silver-and-nickel-filings coherer, with silver electrodes in a sealed glass tube exhausted of air to a moderate vacuum.

A parabolic mirror focuses the waves on the coherer, and metal plates attached to the electrodes are adjusted until the best effect is produced. This adjustment really consists in "tuning" the receiver until the natural period of its electron vibrations is the same as that of the waves, so that electrical resonance occurs.

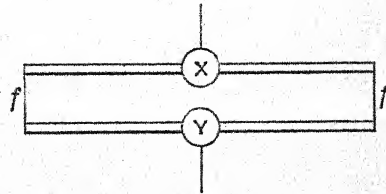


Fig. 144.—Righi Oscillator

LODGE'S METHOD.—Lodge used large conical surfaces instead of the Marconi plates, and a similar oscillator, save that his spark gap was of air instead of oil. His coherer in some cases consisted of a straight piece of watch spring just touched by the point of a needle. The resistance, as with filing tubes, is greatly reduced by the Hertzian waves. Both transmitter and receiver were fitted with the large cones tuned to resound together.

POPOFF'S METHOD.—The next stride was taken by Popoff, who, instead of using plates or cones, attached one pole of his coherer to an earthed plate, and the other to a wire supported on a high mast. This wire or ANTENNA catches up the waves and transmits them to the coherer.

MARCONI'S IMPROVEMENTS.—Marconi adopted this idea, and added an antenna also to the oscillator or sending apparatus. The waves thus obtained are longer and are less obstructed by obstacles in their path, just as long sound waves bend around objects which entirely stop such short

ones as are emitted by high-pitched whistles. In addition, the height of the antennæ helps to carry the waves clear of obstacles.

Progress now became rapid; the large plates gradually fell out of use, and more wires were added to the antennæ to increase their radiating power.

LATER DEVICES have aimed at the employment of greater charges in the oscillator. The increase of size of antennæ is the chief improvement, coupled with the use of more powerful charging appliances. The induction coils have been specially modified for the work in hand by reduction in the number of secondary windings and thickening the iron core; thus the length of the sparks obtainable is lessened, but their crispness and suddenness are improved, and the number passing per second increased.

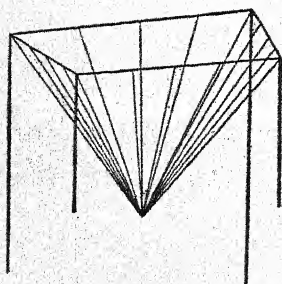


Fig. 145.—Compound Antennæ

USE OF TRANSFORMERS.—When very great power is needed, as in Transatlantic signalling, the induction coil is replaced by a transformer, in which alternating current is raised to a high voltage or pressure. This is applied to a large condenser, and the charge surges in and out of this through the primary of another transformer. The secondary of the latter generates alternating current of higher voltage still, and charges a second smaller condenser, which sends frequent sparks across an air gap, and so sets up oscillations of very high frequency.

These oscillate through the primary of yet a third transformer, whose secondary has one terminal conducted to an earth plate, and the other to the radiating antenna.

The vibrations thus radiated are very little damped, that is to say, each is only a very little weaker than its predecessor. Now this is the condition that resonance shall be good, and that a receiver which is in good tune shall be strongly operated, while an untuned one will remain unaffected.

The receiver has also undergone great changes in recent years, and several entirely distinct types have been evolved.

MERCURY COHERER.—The coherers are perhaps the most interesting, but are now definitely falling out of use. A coherer which regains its sensitiveness without tapping is obtained by using a globule of mercury between two carbon contacts as the sensitive material. The cohesion ceases instantly when the waves stop.

Lodge advances the view that the action of coherers consists in the attraction between the opposite electric charges of adjacent surfaces,

perhaps aided by a sort of welding under the heating action of tiny sparks passing between them.

VREELAND'S ELECTROLYTIC DETECTOR consists of a nitric acid bath with platinum electrodes, of which the anode is extremely small, connected to a battery. When electric waves fall upon this apparatus the apparent resistance of the cell decreases, the effect being far more pronounced even than in coherers; a telephone in the circuit sings loudly whenever the waves arrive.

PRINCIPLE OF MARCONI MAGNETIC DETECTOR.—The Marconi magnetic detector depends on the fact that the changes produced in the magnetism of iron by a variable magnetic force do not occur instantaneously but lag behind the force, while they are expedited by electric waves. A continuous pulley-driven belt of iron wire runs close to the pole of a permanent magnet, and about the wire are lapped two coils, one in the antenna circuit between the mast and the earth, the other connected to a telephone.

When waves arrive, the electric pulse hastens the effect of the magnet on the iron wire, and an induced current flows through the telephone, giving a sound.

SELECTIVE RECEIVERS.—An important phase in wireless telegraphy is the attempt to make a receiver sensitive only to one particular type of transmitter, so that it shall be free from stray disturbance by other apparatus; at the same time the risk of "tapping the wire" by undesirable receivers is minimized.

USE OF PARABOLIC MIRRORS.—Marconi, in his early experiments, used parabolic mirrors, which acted as a megaphone does for sound in directing the waves chiefly in one direction, but modern work would require such enormous reflectors that the method is no longer employed. In warfare or in signalling to ships or moving observers generally it would be of no value.

TUNING SYNTONIC APPARATUS.—The most important means of selective signalling is by use of electrical resonance. By tuning our receiver circuit to the oscillator we can be certain that no other apparatus can read or even be aware of our signals. Lodge and Muirhead's SYNTONIC APPARATUS, already referred to, employs two conical sheets of metal which will only send out radiations of one perfectly definite period. The grave difficulty of syntonick-spark signalling is the difficulty of obtaining trains of waves with very little damping, and at the same time of great intensity. The conditions of tuning and strength are opposed to one another.

SINGING ARC LAMP.—Duddell's discoveries in connection with the singing arc lamp seem to promise a solution of the difficulty. A direct-current arc lamp is joined up with a condenser and a coil of wire. The current chiefly passes through the arc, but part of it surges into and charges the condenser; the latter then discharges itself again through the flame of the arc, and so increases the arc current. Duddell shows that this extra current has the property of lessening the electrical pressure, so the current is next reduced again. A rise of pressure results, again charging the condenser. Thus a sort of see-saw action goes on, the pressure alternately rising and falling, and the current at the other end of the see-saw simultaneously falling and rising. In this way periodic regular fluctuations occur in the current through the lamp. These occur several hundreds or thousands of times per second, and set up two series

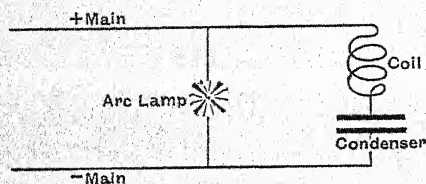


Fig. 146.—Duddell's Singing Arc Lamp

of waves, one in the gas about the arc and the other in the ether. The first are true sound waves, and cause the arc to sing a musical note, quite loud and clear. The others are such electro-magnetic waves as are used in wireless telegraphy; they continue

quite undamped, and can be made of any desired intensity.

They are, however, not rapid enough for use in wireless telegraphy; Poulsen found that if the arc burnt in ordinary coal-gas or hydrogen the frequency is greatly increased. Using such an arc lamp, with its positive rod of copper and its negative of carbon, he obtains waves up to a frequency of a million per second, and these are being used in practical telegraphy with excellent results.

PRACTICAL APPLICATION OF TUNING.—A receiver only detects the waves if exactly attuned to their frequency. Thus, if a number of stations, A, B, C, D, &c., are supplied each with one of these arc-wave producers and with receivers of different frequencies, not all will be affected by a given signal. For instance, A may send out waves to which B is attuned; A's detector and those at C, D, &c., are quite unaffected. The frequency of the waves depends on the sizes of the condenser and coil of wire which produce the variations in the arc; so if we supply the sending apparatus with a variable condenser, A can signal to any one of the other stations without affecting the rest.

The system is in practical use in Denmark, and in England recent Government trials have been quite successful. Signals were sent quite easily from Elmer's End, near London, to Hythe, while instruments at

Dover, quite close to Hythe, were transmitting vigorously in different keys without producing the slightest disturbance in the Hythe instruments.

The application of the method to WIRELESS TELEPHONY is also making considerable progress under the investigations of Poulsen, Ruhmer, and others.

RUHMER'S METHOD.—Ruhmer uses as the transmitter such a hydrogen-flame sensitive arc as has been described, kept silent by suitable arrangement of the condenser. By words spoken into a microphone the current through the arc is caused to fluctuate in step with the sound-waves, and the arc immediately sings out the message quite clearly. At the same time it produces the usual ether waves of the same rapidity, and these travel away to the receiving station, where is set up a coherer in circuit with a battery and a telephone receiver. The fluctuations of current which are produced by aid of the coherer cause the telephone to repeat the message in the usual way.

By a somewhat similar device Oxford and Cambridge may shortly be put into wireless telephonic communication with each other.

CHAPTER XVIII

DYNAMOS AND MOTORS—MEDICAL APPLICATIONS OF ELECTRICITY—ELECTRICITY AND MATTER—PERIODIC LAW—EVOLUTION OF MATTER—STORES OF ENERGY—TRIGGER ACTION—EVOLUTION OF ELECTRONS

The electrical machinery of modern lighting and power installations is described in the section upon Engineering, but it may be well to indicate here the principles on which the chief types depend. The transformer and secondary batteries have already been dealt with; the dynamo or generator of electrical energy and the motor which converts that energy into useful mechanical work chiefly remain.

DYNAMO AND MOTOR—These, often broadly called "machines", are essentially alike. In the dynamo mechanical forces from a steam or gas engine, a turbine or a water wheel, drive the rotating parts, and electric current is thereby generated; in the motor, on the other hand, electrical force expends itself in causing the rotation, and thus does mechanical work. We have, as it were, the two aspects of a business dealing as

they appear in the books of the two firms effecting the transaction. In one electricity is on the debit, in the other on the credit side.

INDUCTION.—The dynamo generates electricity by the action we called the induction of currents. The necessary parts are a system of coils in which the current may flow—the armature; and powerful magnets—the field magnets. Of these two parts one must move past the other,

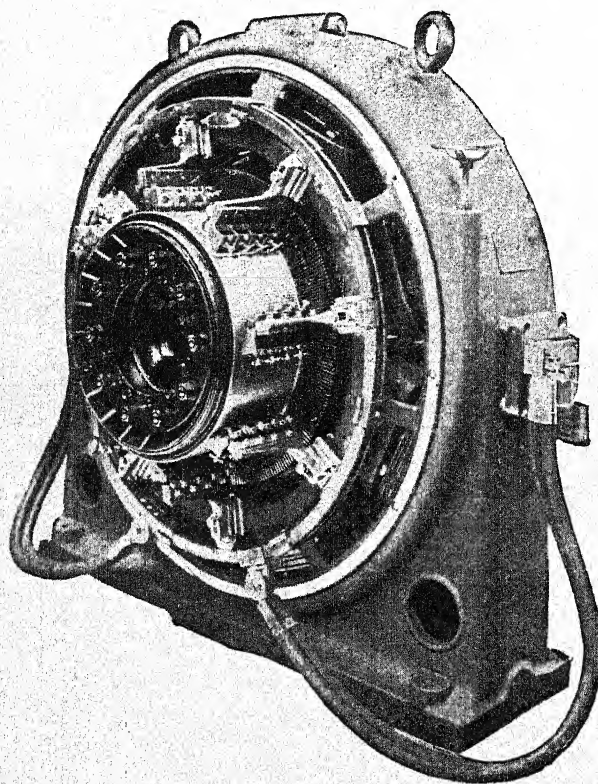


Fig. 147.—Direct-current Generator

the result being that the magnetic force through the armature coils is made to vary, and so electric currents are set up.

In practice the parts are assembled circularly, so that one revolves inside the other; the magnetic force in any one coil of the armature thus fluctuates regularly, and the induced currents flow first in one direction and then in the other. In other words, alternating currents flow in the armature.

COMMUTATOR.—

If it is alternating current that is required,

all that we need to do is to provide cables by which it can flow to the lamps or motors of our installation. If, however, the current must be direct, always in the same direction, we have to rectify the dynamo currents, to add some device to reverse every other fluctuation of the alternating flow in the armature coils. This device is the **COMMUTATOR**; the armature is not joined direct to the cables, but the ends of its coils are affixed to copper strips, the commutator bars, on a cylinder which rotates with the machine. Upon the commutator bars press carbon (or, in small models, copper) conductors, the brushes, which are connected to the mains. Thus, as the armature revolves, each of its coils in turn is con-

nected to the mains first in one direction and then with its ends interchanged. These interchanges, if the brushes are set correctly, can be made to occur just when the current in the coil reverses; in this way, if a brush is at first connected to the positive end of a coil, it is switched

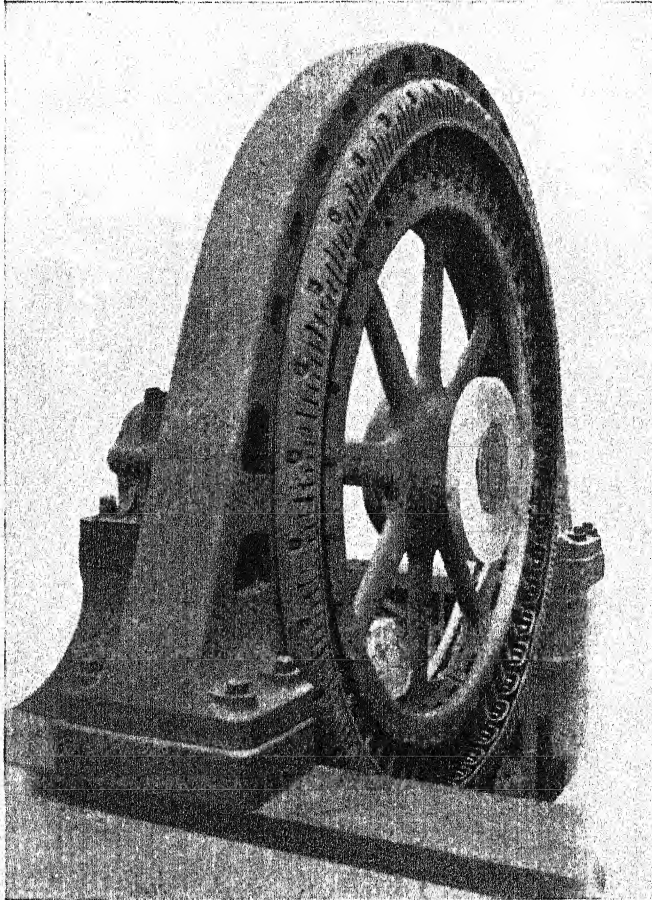
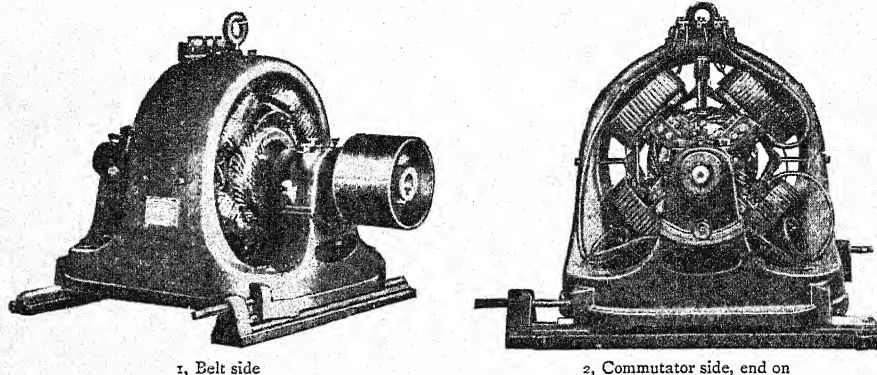


Fig. 148.—Inner Pole Alternator

over to the negative end just as the latter becomes the positive; in other words, the mains receive current always in the same direction.

From this it must be plain that the armature must revolve, and so in all DIRECT-CURRENT DYNAMOS the field magnets are fixed and the armature rotates within them. The standard type is like that shown in fig. 147, where the magnets have several poles, alternately north and south, and are electromagnets, with their currents supplied from the



1, Belt side

Fig. 149.—Direct-current Motor

2, Commutator side, end on

machine itself. The armature has its coils wound over a sort of massive iron drum, which revolves inside the magnet frame.

In the ALTERNATING-CURRENT DYNAMO the magnet must be excited

by direct current, so a separate small dynamo is generally added to produce this. The main machine may roughly resemble the other type, but is now almost always built with its armature stationary, the coils facing inwards wound in slots in the interior surface of an iron cylindrical frame. The electromagnets revolve within, as shown in fig. 148, representing such an inner-pole alternator.

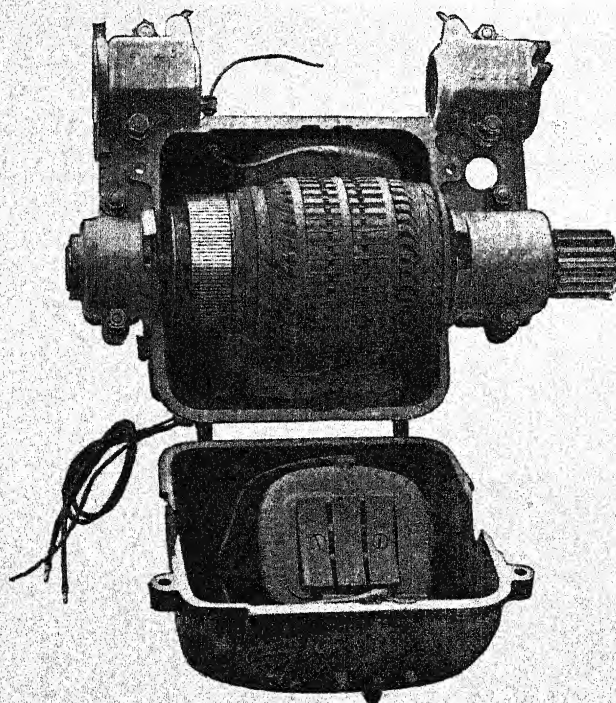


Fig. 150.—Tram-car Motor

MOTORS closely resemble the corresponding generator, direct or alternating, as the case may be; there are in addition several distinct types of alternating-current motor, having no counterpart among dynamos.

Figs. 149-152 represent motors. The general principles of these machines we have already met with in the action of a magnet upon a current-carrying wire which is free to move, or upon the stream of electrons in the cathode-ray tube. Such movable conductors are driven perpendicular to themselves and to the magnetic force; the latter and the conductors (*i.e.* the current) must also be at right angles. If we supply an ordinary dynamo, such as those described, with current from some other independent dynamo or battery, then the armature finds itself carrying current in the magnetic field of the magnets, and accordingly revolves.

A few uses of the motor are illustrated, but an adequate account of its great and varied importance in modern life must be left to the Engineering section.

MEDICAL APPLICATIONS OF ELECTRICITY.—Electricity in medical and surgical use cannot here be treated of with any fullness of detail. In addition to the long-familiar "battery", with its two shock-

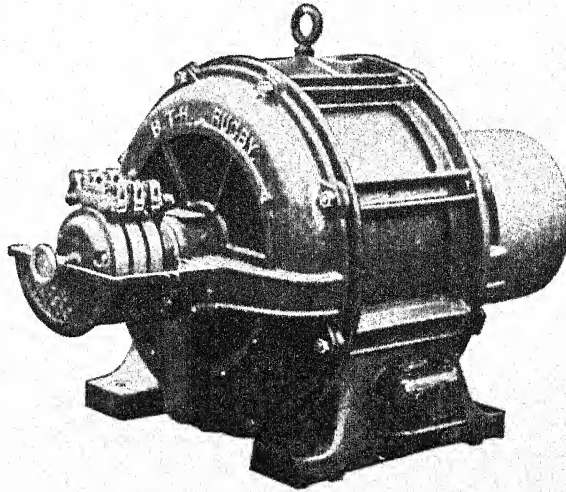


Fig. 151.—Alternating-current Motor

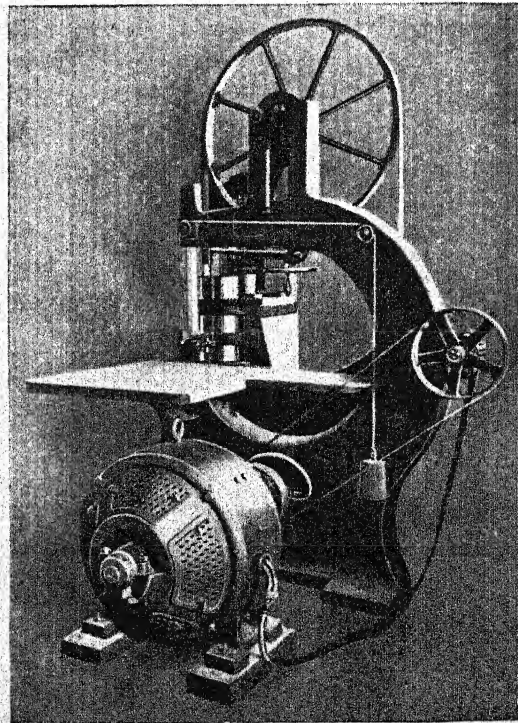


Fig. 152.—Motor driving Band Saw

dealing handles, tremblingly grasped by timid patients, many entirely new nervous treatments are afforded by varied applications of electrical charges or currents.

The "battery" is really just an induction coil whose secondary terminals, connected with the handles or electrodes of the machine, pass the oscillating high-voltage discharge through the arms or body of the patient.

In the various methods, for which the profession insists on retaining such antiquated and barbarous names as Franklinization, Faradization,

and the like, we may, broadly speaking, distinguish two classes—high potential and low potential.

Among the first are the two just named, as is also the quite modern high-frequency treatment.

FRANKLINIZATION AND FARADIZATION.

—Franklinization is the passage of the discharge from an electrical machine, and Faradization of an alternating current, through the tissues

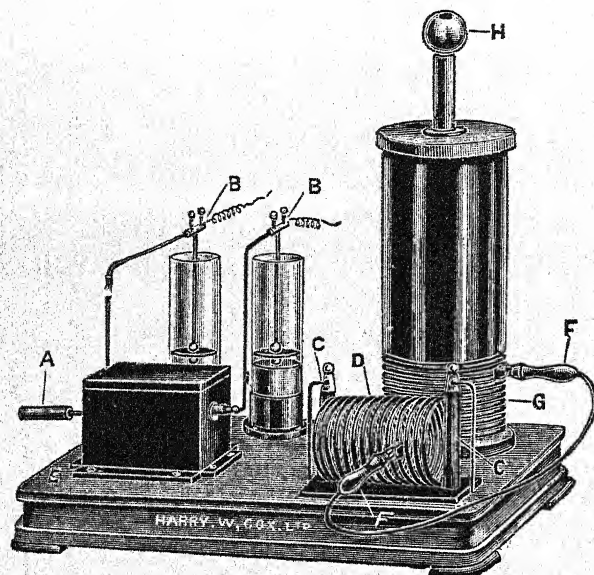


Fig. 153.—High-frequency Machine

to be stimulated. The high-frequency treatment is quite similar to the battery, but with the separate alternations of the discharge recurring in far more rapid succession. This is brought about by an arrangement akin to that mentioned on p. 86 for raising the frequency in wireless telegraphy. The spark from a large coil sets up electric oscillations in neighbouring conductors, and these latter give a discharge alternating many thousands or even millions of times per second. The arrangement, as shown in fig. 153, consists of the coil (in the box A) and two Leyden jars B B, which are merely electrical condensers made up in bottle form, the glass acting as the insulating layer separating the two plates of the condenser, which are tinfoil sheets pasted one within and the other outside on the surface of the glass, on the bottom and halfway up the sides; the whole jars are insulated, and

the inner tinfoil coatings connected respectively to the two terminals of the induction coil. There is also provided a spark gap separating the two terminals. The outer coatings of the jar are joined to the large spiral of copper wire D. The induction coil charges the jars to a certain pressure, and then the insulation of the spark gap breaks down and a discharge passes. This is highly oscillatory in character, and in modern medical apparatus is nearly noiseless, not like the snapping spark of

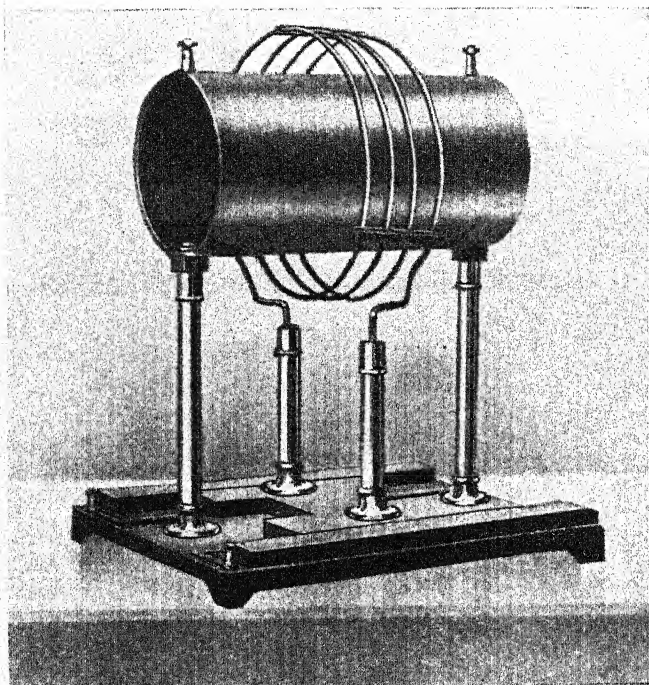


Fig. 154.—Air Transformer for High Frequency

the Marconi sender. It sets up rapid electric surgings in the copper spirals, at the rate of millions per second. The pressure (or voltage) of the discharge is raised by Oudin's resonator, another spiral G, this time of many yards of fine wire wound on an insulating spool (the vertical cylinder). At the bottom one end is joined to one end of the thick-wire spiral, the other end goes to the knob H shown at the top. Another point of the thick-wire spiral is joined to part of the thin coil by the two sliding contacts with handles, seen at the lower right-hand corner F and F. In the best position of these, found by trial, the knob H is surrounded by a purplish glow, and the discharges are of greatly augmented intensity.

AUTOCONDUCTION.—It is only possible to briefly touch upon the chief methods of application of high-frequency currents. In **AUTOCONDUCTION** the large wire spiral is of sufficient size to form a sort of cage surrounding the patient but not actually touching him. The oscillating currents in the coil induce similar currents in the body tissues. In autocondensation the patient grasps one terminal of the coil and lies on an insulating mattress, below which is extended a metal sheet attached to the other terminal. In this way no discharge of electricity occurs, but

charges surge into the patient, alternately positive and negative, millions of times per second. He and the metal plate are the two coatings of a condenser.

In this method, as also in autoconduction, no particular sensation of any kind is experienced, but vacuum tubes glow brightly when held near the patient. The treatment is esteemed for rheumatism, gout, &c., and for tuberculosis.

DIRECT DISCHARGE.—A third method passes the electric discharge directly through the patient by means of the two terminals of the coil, or sometimes, in **MONOPOLAR TREATMENT**, the knob on top of the tall coil is grasped or touched. This method of treatment is especially suited for local application in such cases as lupus, and in the relief of pain resulting from malignant growths.

Only a slight prickly sensation is felt, and yet several ordinary electric glow lamps may be lighted by the patient holding a wire from them, the other wire going to the apparatus.

This is the extraordinary feature of high-frequency treatment, that energy up to a horse-power or more may be passed through the system, and yet no injury ensues; on the contrary, the elimination of waste products is assisted, and many bacilli appear to be attenuated.

ELECTRICITY IN AGRICULTURE.—While dealing with high-frequency currents, it may not perhaps be out of place to mention their effects on the growth of crops. Sir Oliver Lodge has recently made public the result of experiments made on a fairly large scale on a working farm under his direction. The currents were passed through a series of overhead conductors just high enough to permit farm wagons, &c., to pass

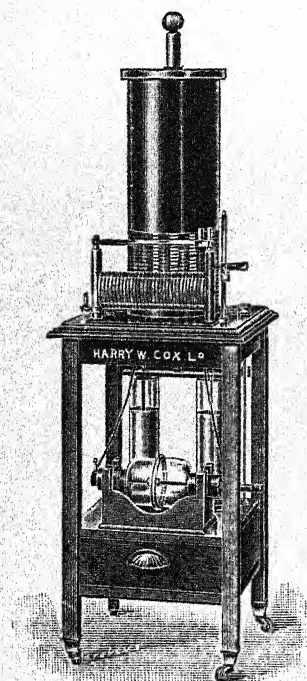


Fig. 155.—Portable High-frequency Outfit

below. Their stimulating effect on the growth of cereal crops is shown by increases of from 20 to 30 per cent in quantity per acre over test crops grown in exactly the same circumstances, save for the electricity. The quality in most cases was also improved.

LOW-PRESSURE ELECTRICITY is chiefly used in medicine in the form of alternating currents, derived from the mains, passed by suitable terminals usually to one limb or the head of a patient; the circuit is completed through the water of a bath. Nervous stimulation is in this way secured quite painlessly.

Electric-light baths, Finsen lamps, and similar devices, strictly speaking, are not applications of electricity, but of light; however, it is convenient to give an outline of them at this point.

The LIGHT BATH is merely a cupboard in which the patient sits and receives upon his skin the light focused by metallic reflectors from a number of ordinary glow lamps.

The FINSEN TREATMENT relies on the ultra-violet rays either of the arc lamp or of such a spark as that of the condenser discharge of high-frequency coils. The mercury-vapour lamp is also employed, and in this instance must be made of uviol glass, a special material far more transparent to ultra-violet light than is ordinary glass.

The usual form uses a powerful arc lamp with iron rods, which produce ultra-violet rays more liberally than carbon ones do, between which the flame plays. The light is passed through quartz lenses (glass is too opaque to the desired rays), which focus it on the part under treatment; the heat, which otherwise would scorch the flesh, is absorbed in the tubes between the lenses by water, which is kept flowing steadily. Such lamps, complete, can now be purchased for about £25, and excellent results have

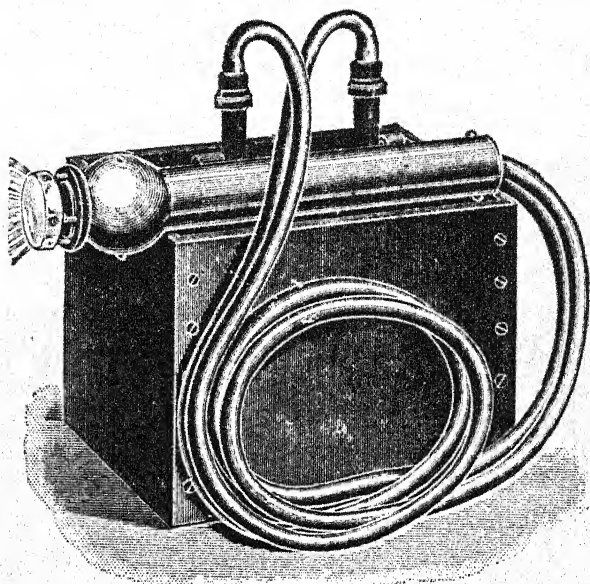


Fig. 156.—Medical Lamp

been obtained by their use in cases of lupus and of ulcers. Smaller battery-lighted lamps are also used (fig. 156).

In surgery the use of the ELECTROMAGNET in the removal of splinters of iron from the eye has already been mentioned, as also that splendid weapon the X-rays, placed by Röntgen in the hands of the medical faculty. Small glow lamps used to illuminate the various internal cavities of the body may also be mentioned, and the heating effect of the current is utilized in ELECTRIC CAUTERY. In this operation, useful in such narrow and inaccessible regions as the nasal passages, the knife is replaced by a platinum wire or loop suited in shape to its particular use, which can be heated by the passage of an electric current. This is led from suitable bichromate or secondary batteries through a holder,

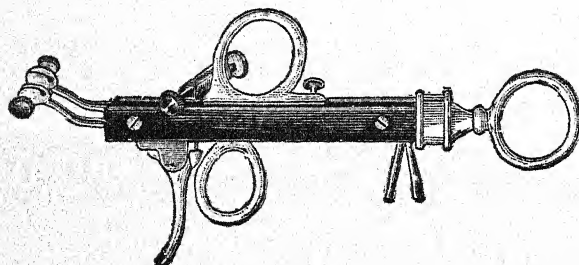


Fig. 157.—Electric Cautery Holder

which combines the handle by which the surgeon directs the cautery, and the trigger switch by which he turns on the current (fig. 157).

J. J. THOMSON'S
RESEARCHES IN ELECTRICITY AND MATTER.

—A most interesting question is raised by the rapid progress of our knowledge of the constitution and nature of electricity—can the properties of ordinary matter be at all accounted for on the hypothesis that the atoms of all elements are built up of electrons moving about a positive larger nucleus or revolving in a positively charged field or atmosphere?

Professor J. J. Thomson has worked out, with remarkable insight and genius, the properties necessarily resulting from some such structure, and his striking conclusions are somewhat as follow. Starting with a combination of a single electron and its equivalent positive carrier, we may suppose the universe made up of a number of such quite simple "atoms". What will happen? These atoms, in their flight, sometimes meet, and may combine under their attractive forces. The electron motions, however, must increase in such a case, for the bodies fall faster and faster towards each other as their distance lessens. Hence an electron may be thrown off by each of the bodies, and the remaining positive nuclei will repel each other. In this case, that is, if the original speeds of the electrons are great enough, two atoms will not unite, and the old atoms will re-form when a wandering nucleus finds a wandering electron.

But the whirling of the electron about the positive "core" necessitates radiation, viz. of the energy represented by the centrifugal force of the spinning electron, and so its speed diminishes, and the time must come when two atoms will unite, and a new atom be formed with a positive "atmosphere" in which two electrons revolve. Radiation proceeds as before, and presently a third electron is added, with the necessary neutralizing increase of positive nucleus. So the process goes on, and more and more complicated atoms appear in the universe; it must be observed, however, that a simpler form will not entirely vanish in the evolution of the bulkier forms, only its slower members succumb to the superior attractions of partnership with each other or with the higher types.

Thus at any time there will be atoms of many distinct kinds in existence; but with the course of ages the simplest types gradually become lost, there is a steady progress towards weightier and more complex forms. The changes may go on less rapidly than in the beginning, because, as Thomson has shown, the radiation of energy from a ring of even a few electrons is vastly less than from a single one rotating unbalanced round the nucleus.

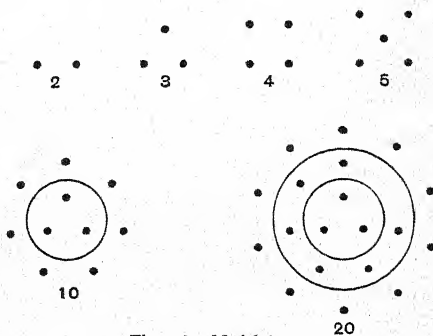


Fig. 158.—Model Atoms

On the hypothesis of electrical mass the motion of a body as well as its charge is necessary for it to have mass at all, so the comparatively stagnant positive nucleus will have but little, and the atomic weight must depend almost wholly on the number of its electrons and their speeds. Thus the hydrogen atom contains about 1700 electrons, while the silver atom holds 180,000, and a mercury atom nearly twice as many.

LOCKYER'S WORK.—This idea of the fundamental oneness of all elements, hazarded as a guess by the alchemists, receives support in another direction in Sir Norman Lockyer's work on the spectra of stars. The hotter stars prove to possess the simpler spectra, made up of lines due to the lightest known elements, while the very hottest show but few lines recognizable as those of any terrestrially known element.

MAYER'S EXPERIMENTS with floating magnets illustrate the definite form of possible configurations of electrons about the atom. He floated varying numbers of little compass needles, resting vertically, so that their north poles are all uppermost, and then studied the patterns into which they united under their mutual repulsions and the attraction of

the south pole of a magnet held just above the water; the south pole represents the positive "atmosphere" in which the electrons move within the atom.

Some of the forms taken are shown in fig. 158. A striking feature is the resemblance between certain sets: thus the figure for 10 shows a triple central set and an external ring of 7; 20 set themselves with the same two inner sets and an outer 10-fold ring. N. R. Campbell tentatively suggests that the number of electrons in the innermost ring may represent the "valency" of the atom.

PERIODIC LAW.—We should expect some similarity in properties, then, between 3-, 10-, and 20-electron atoms, and between these and atoms of greater complexity but possessing the same inner rings. These similar elements should not follow each other in a table arranged in order of increasing atomic weights, but should occur at approximately equal intervals in the table, separated by elements with no such likeness corresponding to the rings with 4, 5, 6, &c., electrons. This is precisely what we find in chemistry in the PERIODIC LAW, as, for instance, in the cases of light fluorine, heavier chlorine, and yet heavier bromine and iodine, the so-called haloids.

The motion of the corpuscles imposes further conditions; it may slightly alter the form of the patterns, but not their general nature. A rotating system, too, may be in equilibrium, which at rest or moving with slower speeds would become unstable and so break up. Thus, in the more complex atoms the radiation which is constantly proceeding, at however slow a rate, must ultimately slow down the rotations of the electrons, and a time may come when instability occurs; the atom rearranges its parts, and may lose electrons and part of its positive nucleus, thus throwing off smaller atoms, and also largely increasing its radiation. So the break-up will produce α - and β -rays, abrupt ether waves, that is, X- or γ -rays, and also the smaller atoms, the emanation; in short, we have almost a complete picture of the spontaneous disintegration of a radium atom.

EVOLUTION OF MATTER.—Physics has thus extended the field of evolution to matter itself, showing that electrons, singly or in combination, may be the underlying reality of all substance. By their motions they produce the mass which has been regarded as the fundamental property of matter. They provide the means of attraction between atoms, and render possible the reactions of chemical change. In their motion from atom to atom, or in free space, they are manifested in the flow of heat or of electricity; their flight around atoms necessitates the expenditure of energy, and so produces the radiations whose rapid waves affect us as

light. The precision of these flights renders the waves so characteristic for each element that we are able in spectroscopy to analyse the stars by means of their light.

The vast STORES OF ENERGY represented by the forces in play between the parts of an atom are at present beyond our grasp. The vastness of the result may perhaps excuse a short calculation. In a hydrogen atom there are 1700 electrons, each having a charge of 3.4×10^{-10} units; the total negative charge then is $1700 \times 3.4 \times 10^{-10}$, or 5.8×10^{-7} , and the neutralizing positive electricity is of like amount. The force between the two is measured by multiplying them together and dividing by the square of their distance, say the radius of the atom, about 10^{-8} cm. This force then is—

$$\frac{5.8 \times 10^{-7} \times 5.8 \times 10^{-7}}{10^{-8} \times 10^{-8}} \text{ or } \frac{(5.8 \times 10^{-7})^2}{10^{-8} \times 10^{-8}}$$

Suppose the parts are dragged asunder against these attractive forces, it will be sufficient to pull them, say, 1 cm. apart; at such a distance the attractions will be negligibly small. The work done is measured by the average force multiplied by the distance moved through, 1 cm. The average force is, of course, much less than the force when the atom was complete, the quantity of the fraction above; but it is greater than the force at the end of the separation, viz. $\frac{(5.8 \times 10^{-7})^2}{1 \times 1}$. We may take in the denominator of our fraction the square of the geometrical average distance, *i.e.* $10^{-8} \times 1$. So the work done is $\frac{(5.8 \times 10^{-7})^2}{10^{-8} \times 1} \times 1$, which reduces to 33×10^{-6} . The units are ergs, but, changing to a more familiar work unit, this quantity is about $\frac{1}{4} \times 10^{-11}$ ft.-lb.

In 1 lb. of hydrogen there are about 3×10^{26} atoms, so by splitting up a whole pound we should have nearly 8×10^{14} ft.-lb. of work; in other words, 3 lb. of hydrogen would produce as much energy as the total yearly output of all the public electric power stations in the kingdom.

TRIGGER ACTIONS.—It may at first sight seem that the conservation of energy demands that we should have to spend an equal amount of work on an atom to break it up, and so should gain nothing. This, however, overlooks the possibility of TRIGGER ACTIONS; the energy is already there within the atom, and the addition of a very little more may cause instability and a general break-up of the atom, much as the small energy of pulling a trigger and exploding a percussion cap liberates the vaster store of chemical energy of the explosive in a cartridge. Hope of such

action upon the atom is afforded by the processes of radioactivity, and still more perhaps by the controllable effect of ultra-violet light upon metals, where it seems possible to supply the "little more" of energy which explodes the atom.

EVOLUTION OF ELECTRONS.—And when we have broken up the atom, when its electrons have become familiar, when the way in which they build up elements is to be read by all on the last-turned page of the book of knowledge, still there will remain uncut the pages which shall tell of the construction and parts of the electron itself; what still tinier and perhaps more active entities build up its bulk, as it builds the atom, and they the planets and suns, themselves but atoms in the vastness of space. So much of the plot of the story we may imagine, though we cannot foretell the manner of its solution; but what further chapters may be in store, what new situations may arise, what new characters appear in the pages we cannot so much as guess.

And not merely in the study of the infinitely little, the atom and the electron, has science extended its borders; in the larger fragments of matter, the heavenly bodies and our own globe, it has found an equally fruitful field of research.

In but a fraction of a century it has weighed and measured sun, moon, and stars, has mapped out and prophesied even the slightest irregularities in the courses of the sun and of planets, has analysed their substance, measured their illuminations, their heat-giving powers, and their temperatures, and probed into the forces which have brought them into being and into their present courses and forms.

CHAPTER XIX

EVOLUTION OF THE EARTH

The NEBULAR HYPOTHESIS has received so much popular attention during recent years that it needs but brief notice here. Suffice it to say that the theory represents a planet as a cloud of heated gases or vapours which, slowly cooling, deposit a liquid core solidifying to a surface crust, and leading to a uniformly tropical climate. The distinct zones only appeared as time crept on.

This theory did not, however, stand the test of a mathematical statement. Its cooling planet is mechanically unstable and improbable. The METEORITIC HYPOTHESIS thus reigned in its stead, according to which a

planet is an agglomeration formed by gravitational attraction of iron or stony meteorites for each other. The comparatively great spaces between adjacent meteorites is a difficulty in the way of such a view, and the PLANETESIMAL THEORY is a later modification, including both the older views. According to this there are local regions of closer packing of meteorites, kinks in spiral nebulae, and these regions have formed the several nuclei of the members of a solar system. The meteoritic view is found by geologists to accord better with the history of our globe as recorded by glacial and volcanic action than does the purely nebular hypothesis. The whole theory, from its Astronomical aspect, has been already treated in Volume I.

The PHYSICS OF OUR GLOBE has made vast strides in the past few years. The form of the earth, the forces which have moulded it into that form, its density, its internal structure, the changes still proceeding in its crust, the electrical and magnetic forces which are dependent upon it, its temperature and that of its atmosphere, its weather and its relations to the sun and its companion planets, all these things have been studied almost from the beginning in the last few decades of the nineteenth century.

SHAPE OF THE EARTH.—The old discovery that the earth is a globe had long ago to be modified to the extent of admitting its shape to be not truly spherical, but that of a spheroid flattened at the poles. Later again we find that the two hemispheres are not symmetrical, but that a slightly pear-shaped body best models our planet, the stalk about the Australian region.

By the figure of the earth, as thus expressed, is meant the smoothed-out figure which we should obtain by extending the ocean surface in all directions through the projecting elevations of land. The peculiarity of shape has resulted from the three facts that every particle of the earth attracts every other particle according to Newton's law of universal gravitation; that all materials yield to some extent, however little, under great compressive forces; and that the earth's substance is not uniform throughout but contains rocks of various densities and various powers of resistance to compression. The net result is a sort of balancing of the forces of gravitation striving to contract the earth towards its centre of gravity against the forces of resistance to further compression of the stuff making up the globe. Where the material is densest, there its inward gravitational pull is greatest; where the compressibility is least, there the increase of density is least. If the earth was formerly in a state sufficiently resembling fluidity to allow us to assume its density to have been everywhere the same, this homogeneity would not remain, but a packing would take place which would end in a form somewhat resembling a one-sided onion, a bulb in which the inmost

core is nearer one side than the other, and this core a little denser than the next coat, this than the next outside it, and so on to the surface coat, least closely packed of all. This is roughly then what we may take the form of the solid earth to be, and upon this more or less spherical figure the surface waters of the ocean rest under the attractive forces of gravity. What form then will these oceans take? It will have the centre of its surface-form at the centre of gravity of the globe. That is to say, more water will rest upon the densest side than upon the least dense; the first will be an area of oceans, the last of continents, if the quantity of water is insufficient to cover the entire surface, as in our case. Thus the Pacific Ocean area overlies the densest side of our planet, the opposite side rising above water level over such vast areas as the Afro-Eurasian continent. This definite division of the globe into a land hemisphere and a water hemisphere is a matter of common remark in our atlases.

But this primary effect of what Jeans calls the gravitational instability of a planet is complicated by the rotation about an axis, and in the earth's case by the pull of the moon.

ROTATION.—The spin of the globe tends to heap up the waters about the Equator, and so to expose the poles as continental areas, a deduction again supported by the facts of the case, the uniform shallowness of our polar seas and the large surface of land in the frigid zones. The rotation also leads to a tendency for the denser parts of the solid earth to be swung farther from the axis under centrifugal force, and this action upon a globe whose centre of gravity is not in the axis of spin must cause "a sort of furrowed surface", as Professor Love points out.

ACTION OF THE MOON.—The effect of the moon is likewise somewhat complex. Von Helmholtz showed that the friction of the ocean tides must apply a braking action to the earth's rotation, and so constantly lengthen the day. Sir George Darwin, in 1879, proved further that the same effect in the moon must not only have slowed down its rotation, but caused it to continually drift farther from the earth. Originally the moon was a part of the earth, which then rotated completely every three hours or so; the immense centrifugal force of such a spin, acting possibly along a flaw in the substance, separated off the moon from its parent planet. According to one theory the bed of the Pacific Ocean represents the scar of this rupture; but, as we have seen, such a violent origin need not be assigned to a pool whose depth is so insignificant as compared with the diameter of the earth.

In any case the moon has drifted away from its old proximity to the earth to its present quarter of a million of miles, and near the beginning

of things its attraction must have pulled the semifluid earth into something of a protuberance on the nearer side. This, Love shows, would lead to further furrowing of the surface by reason of the unequal pulls upon parts of unequal densities.

ORIGIN OF EARTH CONTOURS.—Now, all these actions in their simplified forms can be made the subject of a mathematical investigation—a difficult, laborious, and only approximate calculation, but still a possible one. This calculation Professor Love has made, and finds that the result leads him to a distribution of land and water into a vast continental system spreading from the north polar region to the south by two approximately opposite strips of land. One strip is comparatively simple, trending from north-west to south-east, the other roughly parallel to it, but spread out on its north-western side into a much broader tract, with its western side extending some distance south of the Equator. This distribution is shown in the lower sketch, and it will at once be obvious that the main features of the earth's land and water systems are strongly suggested. The first oblique land area is the American continent, the other the Asian and Australian, with the European and African as its western annexe. The state of things, in fact, is much what we should find if we could remove the ocean to a depth of some 10,000 ft., a state represented in the upper diagram.

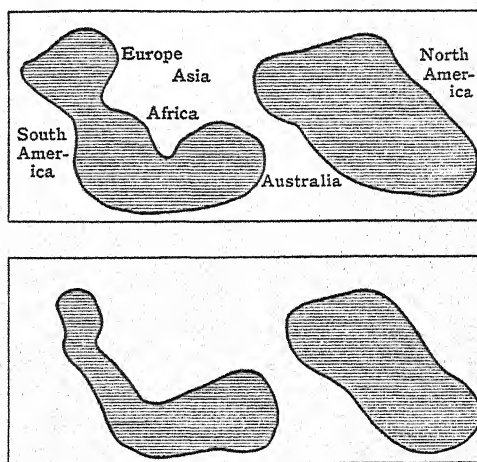


Fig. 159.—Earth Contours

The average DENSITY OF THE EARTH has been the subject of many investigations, of which those of Boys are typical in ingenuity and delicacy. He suspended horizontally, by one of his extraordinarily fine quartz fibres, a light rod carrying a small ball at each extremity. Near each, in the positions indicated, he placed other balls. The attractions between the balls turned the whole suspended rod in the direction of the arrow through a very small angle against the twist of the quartz thread. From the amount of twist he could measure the gravitational attraction between the balls, of known masses and distance apart. Then the problem becomes merely a proportion sum: If such an attraction is the force at

such a distance between such and such masses, what mass in the earth itself will produce a pull of 1 lb. weight on each 1 lb. mass of substance at the surface? The answer is, nearly six thousand million billion tons, representing a density of some $5\frac{1}{2}$ times that of water. This is the so-called problem of "weighing the earth".

This $5\frac{1}{2}$ represents only the average density. Rocks of the surface layers, as we know them, are much lighter than this, not more than three times as heavy as water. The interior layers are denser because of the vast forces of compression to which they are subjected. Are these internal layers of the same matter as the surface crust? Are they, like it, heterogeneous and varied, or have we anything corresponding to the fiery fluid core with which old theories endowed the earth?

The evidence appears to indicate a depth of 40 miles or so as the maximum possible for the surface rock crust; below this is a core of

uniform structure, though what that structure can be we can hardly guess; a certain amount of evidence points to nickel-iron meteorites as its prime materials. All we know is that, so far from being an ordinary liquid, it possesses a rigidity about equal to that of steel. The



Fig. 160.—Weighing the Earth

arguments which have led to these conclusions are chiefly drawn from the facts of radioactivity, of earthquakes, and of the variations of the strength of the earth's gravitational attraction evidenced by the different times taken by the swings of a pendulum at different points on the globe.

The denser the material underlying the pendulum station the greater will be the pull on the bob, and the faster will be the swings. If an abnormally dense stratum is thus detected, we may often at once surmise from the small surface area affected that the layer is not deep seated. A confirmation is afforded by the plumb line. This, if brought near a mountain, does not hang truly vertical, because of the pull sideways of the mountain upon the plumb. So also a neighbouring dense portion of the surface crust will draw it aside, but a deep-seated portion cannot appreciably do so. It has been observed that a deviation of the plumb line almost invariably occurs in places near those of exceptionally quick pendulum swings.

The EARTHQUAKE RECORD is this: The speeds with which earthquake waves travel are greater as the recording station is more distant, up to a certain point. At all distances beyond this the speed is constant. This

accords with the supposition that a surface layer of ordinary rock allows the waves to travel with a certain speed, depending much on their nature; but below these rocks comes a substance permitting a much higher speed of wave travel, and that speed always and everywhere the same. The uniformity of speed denotes uniformity of medium, and the greatness of speed a high rigidity for that medium; in fact, as above stated, a rigidity as great as that of steel. The distance beyond which uniform earthquake wave speed is recorded is that which brings the straight line, the chord of the sphere in which the waves travel, some 30 miles below the surface.

The evidence from radioactivity is that the temperature of the earth would be maintained as we know it by the radium contained in a volume about one-thirtieth that of the whole earth; this is on the hypothesis that the distribution of the radioactive substances is everywhere about the same as that in the many surface specimens hitherto examined. Now, one-thirtieth of the earth's bulk is contained in a skin about 40 miles thick. The assumption thus made is that the lower regions are a uniform core free from radium and its congeners.

The evidence of the small distortion of the bulk of the earth under the tidal pulls of the moon leads also to the conclusion that our planet is as rigid as steel.

The MAGNETIC STATE OF THE EARTH is a subject of the highest interest and practical importance. The use of the mariner's compass in navigation is rendered possible by the fact that the earth behaves as though it contained a powerful magnet whose south pole were somewhere in the northern direction and its north pole in the southern. Hence the compass needle has its north pole drawn northward and its south pole to the south.

The phenomenon of DIP shows us that the magnetic force of the earth is not horizontal, however. If we pivot a needle about a horizontal axle through its centre of gravity, it will rest in any position to which it is turned—horizontal, vertical, or oblique. If next we magnetize the needle and set it so that its plane of swing is north and south, we find that in northern latitudes its north pole dips downwards, while in the southern hemisphere it is the south pole which dips. In England the dip of the north pole is about 70 degrees, in Australia 60 degrees, but with the south pole down; near the poles the needle sets vertically, that is to say, the dip is 90 degrees, while near the Equator it is *nil*, or the needle lies horizontally. This indicates the inclined direction of the magnetic forces at most points upon the earth's surface, and from the amount of the dip it appears as though the earth-magnet were small and lay at the centre of the globe, nearly along the line of the axis of our planet's rotation.

Exact measurements lead to modifications of all the above statements: the compass does not point truly north, but either east or west of north in most places, by a small angle called the Declination. In England it is about 17 degrees west of north. The dip is 90 degrees, not at the actual north and south poles of the earth, but at the so-called magnetic poles, some degrees removed, one in Boothia Felix, off the Arctic coast of America, the other in the Antarctic, south of Australia.

In fact the best magnetic model we can make of the earth must contain two magnets, so great are the irregularities. One, the stronger, points along a line from the extreme north of North America to southern Australian seas, the other from Northern Siberia to nearly the same southern pole.

ORIGIN OF TERRESTRIAL MAGNETISM.—Whence comes this magnetism? It cannot be from actually magnetized rocks embedded in the earth, for the forces are by far too great to admit of such an explanation. Only a surface shell of the globe could be thus magnetized, for iron and its compounds lose their magnetic properties at a bright-red heat; and the temperature for this is reached only a few miles below the surface. In the shell thus supposed there would have to be embedded powerful steel magnets at the rate of hundreds to the cubic mile to produce forces of the magnitude of those which act upon our compass needles. No rock in the earth's crust can be magnetized to an amount approaching that possible for iron or steel, so the permanent-magnet hypothesis falls to the ground.

The only other means we know of producing magnetic force is the electric current, and here the temperature difficulty is at once removed. There is no reason why the whole interior of the globe should not be available as the conductor in which the necessary currents flow; such oxides as those of the rare earths used in Nernst lamp glowers, and indeed most non-metallic bodies, conduct electricity far better at high than at low temperatures. The direction of the currents must, as we have seen, be such that they produce a south magnetic pole in northern latitudes; that is to say, the line of flow must be round and round the globe parallel to the Equator in a direction from east to west, the direction opposite to that of the earth's spin. Add to this the probability that the currents, like most other electric currents, are due to moving electrons of negative charge, which therefore travel from west to east as the earth travels, and it becomes almost certain that the spin of the earth upon its axis must in some way generate these currents. Experiments have been attempted by which to test whether all revolving conducting spheres

are magnets, but with no success. However, the conditions of the vast mass and speed of the earth, and of the interactions between it and the ether, are so impossible of reproduction in the laboratory that continued negative results can never disprove the theory that the earth is a magnet by virtue of its rotation.

No definite evidence of currents of the required strength and regularity has come to light. Irregular surface currents are well known, the earth currents, which cause much trouble in telegraphy. But these are fitful, and as a rule flow in wrong directions, so that at best they can be regarded but as outposts of the steadily flowing currents within.

SECULAR CHANGE IN TERRESTRIAL MAGNETISM.—The earth's magnetic forces are subject to many variations, regular and irregular. Of the first class the chief is a secular change going on in the direction and to some extent in the strength of the forces, represented by a slow wheeling of the magnetic poles around the geographical ones, a motion apparently to be completed once in about every 360 years.

OTHER PERIODIC CHANGES IN TERRESTRIAL MAGNETISM.—Of less note are daily, monthly, half-yearly, annual, and eleven-yearly periodic changes, arising from extra-terrestrial causes. The first is produced by the daily progress of the earth under the sun. The place at which the sun is in the zenith naturally becomes most strongly heated; there, accordingly, evaporation of water proceeds most rapidly, and it is an ascertained fact that the vapour rising from water is electrically charged. Hence hot electrified air rises from the Tropics and flows as a hot high-level wind towards the poles to supply the deficit caused by cool air lower down which has gone towards the Tropics to fill its place. Hence there are practically currents of electricity in the atmosphere, which sweep around the globe each day, causing day-period perturbations of the compass needle.

The monthly and annual periods, respectively, depend on the moon's and sun's proximity. The half-yearly variations correspond to a period of alternate maximum and minimum radiation from the sun. The sun's axis is not perpendicular to the plane of the earth's orbit, the ecliptic, so he presents his polar regions most towards us at six-monthly intervals. Now these regions are hotter than those about his Equator, hence his warmth to the earth and the evaporation this produces show a half-yearly fluctuation.

The eleven-year period corresponds to that of maximum sun-spot activity, and these times also coincide with maximum solar radiation.

In addition to these regular changes, magnetic storms or irregular

disturbances are of occasional occurrence, and produce such great effects that telegraphic communications may be interrupted by the violence of the swings of the magnetic needles of the instruments. These storms also occur more commonly at maximum sun-spot display, and most of all when a spot faces directly towards the earth. They appear to be due to veritable electric cyclones produced by the unusually strong solar radiation in the upper regions of the atmosphere.

AURORÆ.—Coincidentally with magnetic storms there frequently appear those beautiful flickering gleams known as the Aurora Borealis or Australis (northern or southern lights). These also sometimes occur without magnetic storms, but still show some connection with terrestrial magnetism, being centralized around the magnetic poles of the earth, and exhibiting the same eleven-year periodicity.

Extraordinary as it may appear, there is good reason to suppose that the grandest type of these displays are electrical discharges akin to those of vacuum tubes, excited by the passage of cathode rays sent direct from the sun.

They are beyond doubt electrical in character, for many of their appearances have been artificially reproduced in the Arctic zone by the working of an electrical machine near a mountain peak or connected to a pointed wire thrusting up into the atmosphere. The soft colours of the displays, too, strongly suggest the vacuum tube.

But the clearest confirmation, as pointed out by Arrhenius, lies in the SPIRAL AURORÆ which sometimes appear, the axis of the spiral then being the direction of the earth's magnetic force. It will be remembered that a current free to move will set itself at right angles to lines of magnetic force. Thus if a sunspot points to the earth, the electrons liberated by its tremendous and flaming activity (electrons are produced even by ordinary flames) travel out with great speed as veritable cathode rays through the vacuum of space until they approach our globe. Here they come under the influence of our magnetic force and try to set themselves at right angles to its direction, coiling themselves about it. Along their spiral path they collide with the molecules of the rarefied air of the upper atmosphere, causing luminescence in every way akin to that in the vacuum discharge tubes of our laboratories.

GRAVITATION itself, the force by which every particle of matter in the universe attracts every other particle, was discovered by Newton two hundred and fifty years ago, but is still unexplained. Many suggestions have been made to account for it, of which one of the most interesting is that of le Sage. He supposed all space to be full of bombarding particles

of something moving in all directions with great speeds, and, by their impacts on bodies, producing a pressure. A single body in free space must experience this pressure evenly on all sides, but as soon as a second body is brought near, it screens the first to some extent from the bombardment from its direction, and is similarly shielded by the first. Hence the forces on the sides of the bodies facing each other are reduced, and the bodies are urged towards each other by the excess of pressure on their outward faces.

It is easy, too, to see that the closer together the bodies the greater the number of bombarding particles they must screen off—in other words, the greater their apparent attraction for each other.

The hypothesis in some ways recalls the light pressure which we have shown to be experienced by all substances upon which radiation falls, but this pressure is far too feeble to explain gravitation, and no other hint of le Sage's projectiles has been discovered.

THE ETHER AND GRAVITATION.—It would appear almost certain that the ether of space is in some way the vehicle of gravitational force. It is the only medium stretching between the heavenly bodies, and all our past experience has gone to show that interaction between two separate bodies can only take place through some link of communication: the coupling between the engine and its train, the air between a sounding body and our ears, the ether between the sun and our eyes, or between a distant wireless telegraphic station and our receivers. Sutherland has shown that if, as may well be possible, there is a very slight excess of attraction between two unlike charges over the repulsion between two equal like charges of electricity, if an electron attracts a positive nucleus rather more strongly than it repels an equally distant companion electron, then this excess of attraction applied to the myriads of electrons and positive nuclei making up matter may explain gravitation. The surplus attraction per electron may be minute though calculable, the total of the quadrillions of electrons making up our globe may yet bring about the forces we know as the earth's attraction, the weight of bodies.

FURTHER ADVANCE IN PHYSICS.—It has fallen particularly to the lot of physics in late years to become the playground of newspaper scientists, whose fertile imaginings have answered questions which with real study of the subject could never have been asked. Nevertheless, imagination is required for true progress—but a disciplined imagination, applied to the interpretation of well-ascertained bodies of fact. We may be confident that further advance in physical knowledge will come, as it has always done in the past, from this method of which the electron theory

affords so typical an example. Newly discovered phenomena led to provisional hypotheses, which in turn had to stand the test of keen scrutiny and application to other fields of knowledge. The best of these hypotheses not only withstood the ordeal but led to new deductions subsequently verified by experiments of many kinds; that is the justification for their acceptance. A single failure in ability to explain any given phenomenon may bring about revision, a contradiction of any large body of fact must lead to rejection—here in epitome lies the history of science and of the triumph of scientific method.

[The author wishes to record his gratitude to Mr. Stansfield of Manchester University for permission to reproduce his remarkable photographs of soap-films, and to several firms for the use of process blocks: Messrs. Cox, W. & J. George, Drake & Gorham, Krupka & Jacoby, F. Ernecke, Philip Harris, the Cambridge Instrument Company, and the British Thomson-Houston Company.]

LIST OF PHYSICAL SCIENCE WORKS RECOMMENDED FOR FURTHER STUDY

Name.	Author.	Publisher.
<i>General—</i>		
TEXTBOOK OF PHYSICS . .	Prof. W. Watson	Longmans, Green & Co.
THE RECENT DEVELOPMENT OF PHYSICAL SCIENCE }	W. C. D. Whetham	John Murray
MODERN THEORY OF PHYSI- CAL PHENOMENA }	Prof. Righi	Macmillan & Co.
THE EVOLUTION OF MODERN PHYSICS	Lucien Poincaré	{(International Science Series.) Kegan Paul, Trench, Trübner & Co.

Properties of Matter, Sound, Light, and Heat—

THE PROPERTIES OF MATTER	{ Prof. J. H. Poynting and Sir J. J. Thomson }	Griffin & Co.
SOUND AND MUSIC ...	Sedley Taylor	Macmillan & Co.
PHYSICAL OPTICS	Prof. R. W. Wood	Macmillan & Co.
LIGHT	Lewis Wright	Macmillan & Co.
LIGHT WAVES AND THEIR USES	Prof. A. Michelson	Chicago University Press

Electricity and Magnetism, Radioactivity, and the Electromagnetic Theory of Matter—

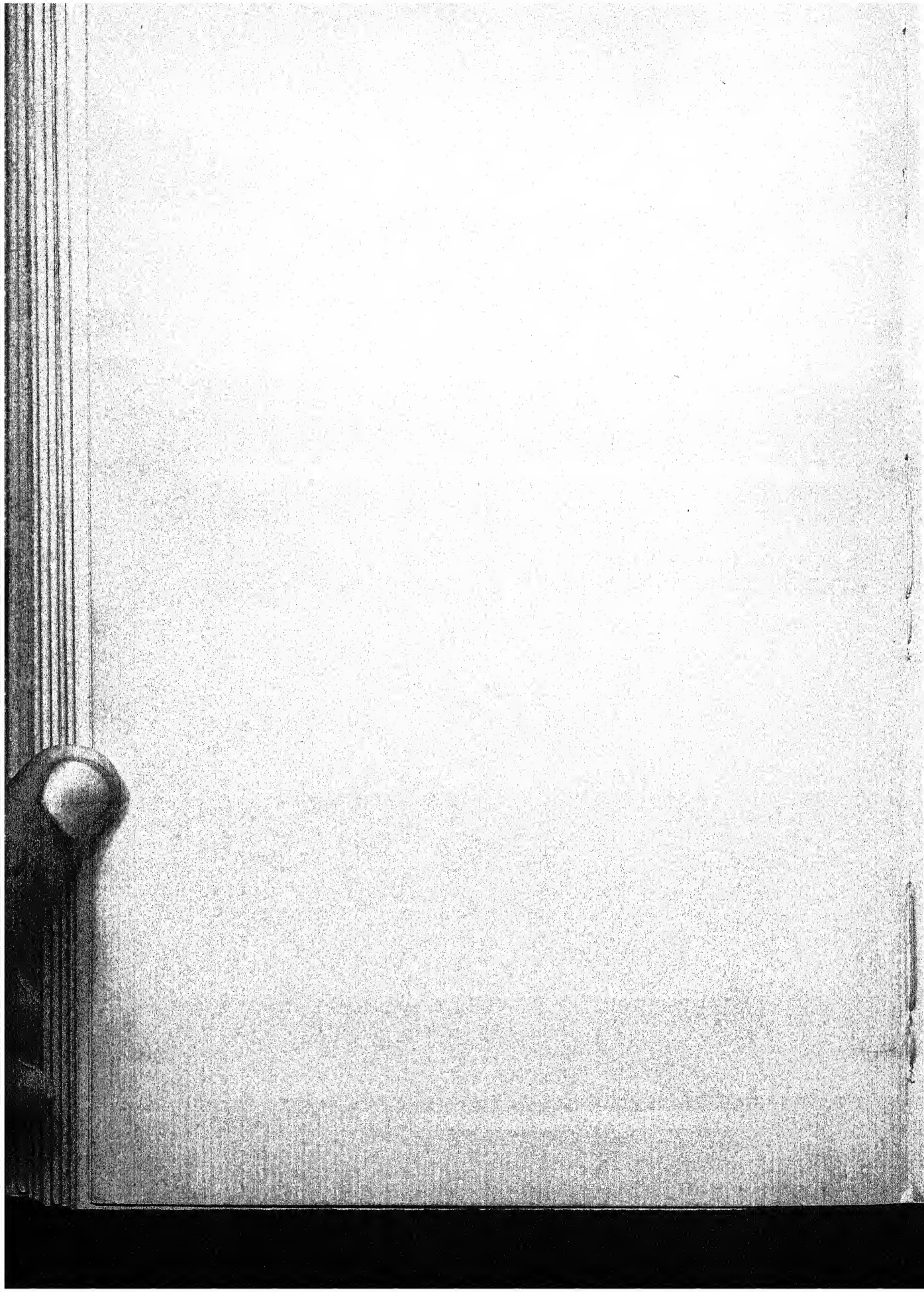
MODERN ELECTRICAL THEORY	Norman R. Campbell	Cambridge University Press
MODERN VIEWS OF ELEC- TRICITY	Sir Oliver J. Lodge	Macmillan & Co.
ELECTRONS	Sir Oliver J. Lodge	George Bell & Sons
THE ELECTRON THEORY ...	E. E. Fournier d'Albe	Longmans, Green & Co.
ELECTRICITY AND MATTER	Sir J. J. Thomson	Arch. Constable
THE CORPUSCULAR THEORY OF MATTER	Sir J. J. Thomson	Arch. Constable
THE CONDUCTION OF ELEC- TRICITY IN GASES }	Sir J. J. Thomson	Cambridge University Press
RADIOACTIVITY	Prof. E. Rutherford	Cambridge University Press
THE EVOLUTION OF MATTER	Gustave Le Bon	Walter Scott
THE EVOLUTION OF FORCES	Gustave Le Bon	{(International Science Series.) Kegan Paul, Trench, Trübner & Co.
ERDMAGNETISMUS, ERD- STROM UND POLARLICHT }	A. Nippoldt	Goschen

GENERAL BIOLOGY

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GENERAL BIOLOGY

CHAPTER I

INTRODUCTION—PROTOPLASM AND ITS PROPERTIES—HABIT AND REACTION—MANIFESTATIONS OF LIFE

INTRODUCTORY

Though we still know so little of the beginnings of life, science has certainly advanced a great deal since the old days of a casual half-belief in the genesis of flies from putrid meat. Not science alone, but civilization as well, owes a great deal to the surgeons of the nineteenth century, among whom may be named Lord Lister, the pioneer of antiseptic precautions, and Pasteur, who devised methods of sterilizing milk and other substances. These researches made it possible to control to a great extent the growth and multiplication of minute forms of life such as bacteria and infusorians. From the results obtained it has been possible to make the broad inference that a living organism typically arises from a pre-existent organism. If, however, this principle of BIOGENESIS were conceived in the form of an absolute law, equally applicable to the present, past, and future, if life must always have come from life, the problem of the origin of that quality would be beyond the scope of scientific research.

It has always been found impossible to state exactly what is meant by life, for various properties of a living organism also occur in other bodies which cannot be said to be alive. Crystals grow, and it is possible to make drops of certain emulsions move towards or away from various solutions, and so on. Science is therefore trying to work towards what Spencer called a proximate definition of life by studying the various activities and the structural features of bodies possessing that mysterious quality.

The typical unit of life is usually called a CELL, though the name

ENERGID, proposed by Sachs, would be far more suitable. Living organisms are either single cells or aggregates of cells united to form a larger body (figs. 163, 175, and 176), and it therefore seems justifiable to search among one-celled organisms for hints as to the structure and activities of the most primitive of living things. Any organism now living will, of course, be likely to differ very considerably from the first living things which appeared on earth, for the history of life on earth goes back perhaps more than 100,000,000 years, and it is unlikely that any types have survived such an immense period of time without change. Still, the fact remains that, in spite of multiform diversity, the essential substances of living organisms are sufficiently alike to be grouped together under the name of protoplasm.

PROTOPLASM

The name of PROTOPLASM is employed to designate intricate mixtures of the most complex class of carbon compounds when those mixtures exhibit the properties which are characterized as life.

CONSTITUTION.—It is more than probable that the constitution of the mixture varies with every type of life examined, and it may also vary in a lesser degree from one individual to another of the same type.

The carbon compounds present in the protoplasm typically contain the elements known to chemists as carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, potassium, magnesium, and, very often, iron, in addition to small quantities of still other elements. Their molecules are very large and complex, and are said to be in a COLLOID state.

COLLOIDS AND CRYSTALLOIDS.—Molecules in a colloid state have two noteworthy characteristics:

1. They decompose fairly easily, liberating energy as they break down into simpler bodies.
2. Many of them are unable to filter through a membrane.

The name CRYSTALLOIDS is given to substances like the soluble salts of many metals when their dissolved molecules, or perhaps rather IONS, are able to pass through an ordinary membrane. A colloid cannot do this, and by minute investigation it has been found that colloids are made up of very small particles closely set but surrounded by a fluid. The particles, in their turn, are usually made up of large and complex molecules.

If we imagine a colloid mass lying in water, its particles will not tend to separate and diffuse through the water as would those of a crystalloid mass. The aggregate therefore possesses a certain durability, and into it is penetrating all the while any material held in solution by the water.

On the other hand, the instability of the colloid molecules leads to their decomposition; but the incoming material may combine with some of them or their decomposition products, and so may help to rebuild the mass. The reactions which rebuild (synthesize) use up the energy set free in the reactions of decomposition, and so at the best the building process will not do more than make good some of what is lost in decomposition.

Still, we see that, given colloid aggregates, a certain amount of chemical exchange is possible without their immediate decomposition, and we thus obtain a speculative basis for the study of some of the steps in the probable course of the evolution of life.

Nothing is known of colloidal carbon molecules occurring in nature apart from living organisms and the effects of their activity, but the related element silicon forms many colloidal compounds, and it is the most characteristic element of the earth's crust. One may thence hazard the guess that under some unknown conditions carbon compounds of this nature came into existence; one of these conditions was no doubt the existence of water at a temperature between 0° and 60° C.

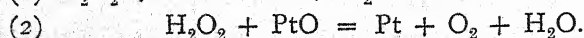
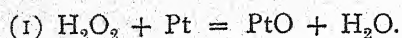
OSMOSIS.—If, then, we suppose a colloidal mass in water, we understand that dissolved material will penetrate into the mass until the solution of the material in question is as concentrated within as it is outside the mass. Further, any diffusible compounds found or formed within the mass will diffuse out until concentration is as great outside as it is within. These two processes are called respectively endosmosis and exosmosis.

The endosmosis of any particular substance can continue for an indefinite period if that substance is chemically altered after it has filtered in, for the limit of concentration is never then attained; and so we may suppose a colloid aggregate long continuing to absorb certain substances, using them in chemical reactions to build up new molecules within the mass. Here it is that the difficulty comes in, for the upbuilding uses energy, and the only source of energy so far suggested is that derived from decomposition of other colloid molecules.

GROWTH.—When now we study living organisms, colloid aggregates which are alive, we find that many of them, the typical plants for example, possess compounds with various colours, more especially green, which absorb the energy of the sun's rays, and particularly of the heat-bearing rays. The energy thus obtained is utilized in the upbuilding reactions already mentioned, which can by this means predominate over the reactions of decomposition. We are thence enabled to speculate with regard to a similar step in the original colloidal aggregates from among which living organisms are supposed to have been evolved. If some of them

came to include molecules with pigment which would absorb solar energy, they were no longer restricted to a very transitory existence during a perhaps more or less delayed process of decomposition. The regular absorption of energy made continued growth possible. There may be other ways in which energy is absorbed by living organisms of which as yet nothing is known.

Another possibility with regard to protoplasm and growth has been suggested by F. F. Blackman and others in recent years. It is a well-known chemical fact that reactions may be greatly accelerated through the addition of special substances, though these substances remain apparently unchanged at the end of the experiment. Thus, black oxide of manganese (MnO_2) promotes the decomposition of potassium chlorate (KClO_3), and platinum black breaks down hydrogen peroxide (H_2O_2). In the latter case it is probable that reactions occur as follows:—



Agents like platinum black are called KATALYSTS, and it is suggested that protoplasm may be a KATALYST promoting the upbuilding chemical reactions which characterize living organisms. But, as some of these reactions result in the formation of new protoplasm, the amount of the katalyst increases, and so does its katalytic influence. The new added protoplasm quickens the rate of accumulation, so the increase is in geometrical progression; the process is continuously accelerated. As the early stages of growth of organisms under normally favourable conditions shows this acceleration very clearly, the theory has some probability. In any case, however, it seems impossible to dispense with some supply of energy from the exterior, and for this we are thrown back in most cases to the suggestion of its derivation directly or indirectly from the sun's rays.

DIVISION.—Growth obviously depends on the surplus of income over expenditure of material. Now the income, as Herbert Spencer suggested, is proportional to the surface through which absorption can take place. Surface in its turn is proportional to the second power of the linear dimension.¹

On the other hand, the tendency to break down is likely to be felt throughout the volume, and volume is proportional to the third power of the linear dimension.² The result is that, with increase in size, volume

¹ Surface of sphere = $4\pi r^2$.

Surface of cube = $6s^2$.

Surface of cylinder = $2\pi(rh + r^2)$, and so on.

² Volume of sphere = $\frac{4}{3}\pi r^3$.

Volume of cube = s^3 .

Volume of cylinder = $\pi r^2 h$, and so on.

increases much faster than surface, and in this way expenditure ultimately overtakes and gets ahead of income. This final bankruptcy through overgrowth has been avoided in successful forms of life by the appearance of the habit of division. It is thus just possible to frame a few, necessarily vague, ideas about the origins of the processes of chemical exchange, growth, and division in primitive living organisms. But one need only think of even the simplest organism with its incredible complexity of structure and function to realize that the few hints which research and scientific discussion have gathered together are the merest gleams in the darkness of the problem, which is thereby rendered only the more impressive.

HABIT AND REACTION

SEQUENCES OF ACTION.

—Perhaps the most noticeable feature about all living things is that there must have been a gradual regularization of all the processes connected with their vital activity, and these regular sequences of events tend to recur in due order. The living substance in

some way retains an impress—ENGRAM is the word used by Semon—of what has once occurred, and this leads to the recurrence of the chain of events when circumstances give that sequence a start. An oft-quoted analogy is that of the switch turned on to make a complete path for the electric current which will start dynamos that supply power for all kinds of work. The dynamo and the machine which does the work are all in position, and when the turning of the switch gives them the start a whole chain of events follow. Then not merely the small amount of

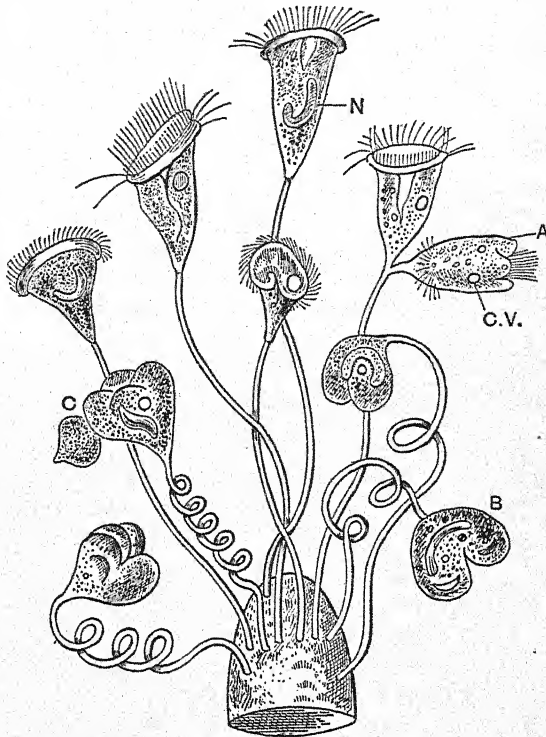


Fig. 161.—Vorticella in Reproduction

N = Nucleus. C. V. = Contractile vacuole. A, An individual in process of separation by longitudinal fission and developing the posterior circlet of cilia for the free-swimming life. B, An earlier stage of longitudinal fission. C, A free-swimming individual conjugating with a stalked individual.

energy given in turning on the switch, but also a much greater quantity of energy generated in the working of the dynamo, is transformed into the work of lighting a town perhaps, or of driving a lathe or even a locomotive. It would not be wise to apply such an analogy in detail and to imagine a mechanically intricate arrangement within the primitive living organism, but the structure of all forms known to us is wonderfully complex, and their responses to changes in their circumstances more wonderful still.

FIXATION OF HABITS.—It is characteristic of even the simplest living things that the sequences of action they go through when their circumstances change have a value for their lives. In other words, their habits of retreat from unfavourable circumstances, and so on, are usually such as tend to ward off death and destruction. So we are tempted to imagine that these sequences or habits have become fixed through the survival of their possessors, while other bodies evolving towards life came to grief for the want of them.

EVOLUTION OF COMPLEX HABITS.—External circumstances change, and the changes stimulate the activities of the living organism; in surviving, and therefore in a measure successful, forms those activities lead the organism to readjust or adapt itself to its altered surroundings. When a daisy closes its ray florets to protect the disc from dew or rain, or when a herd of deer seek safety in flight from a beast of prey, the stimulus is very complex, and so is the response, the readjustment, involved; but we must suppose that these highly complicated habits have evolved in the course of time from simpler ones, and so on backwards, step by step, to the mysterious beginnings of habit in the mass of albuminoid molecules evolving towards the quality of life.

HABITS OF SIMPLE ORGANISMS.—Jennings has conducted researches into the behaviour of one-celled organisms, chiefly infusorian animalcules, and has shown that many characteristic points of that behaviour are traceable to the chemical composition and almost imperceptible variations of the chemical composition of the solutions in which they live (fig. 162). In this case, then, we are in contact with a fairly simple stimulus, and perhaps the response is also not very complex. Much harm has been done to science by describing the behaviour of the simpler organisms in terms which are appropriate only to the discussion of the habits of mankind, and probably only of more or less civilized peoples.

MECHANICAL THEORIES OF LIFE.—The opposite error, of describing the activities of living organisms as though known chemical and physical laws gave a complete account of them, is also dangerous. It has just

been said that the living organism in some way retains an impress (engram) of what has happened to it, and that this engram affects its future behaviour—even, perhaps, that of its descendants, according to Dr. Francis Darwin and other biologists. This implies that factors within the organism, which may or may not be expressible in chemical terms, exercise at any rate a controlling influence, and this is considered so important by many naturalists that they urge rather the study of

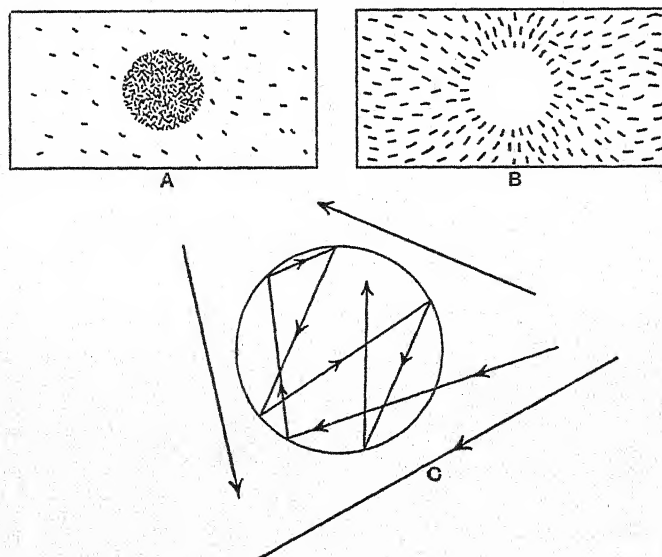


Fig. 162.—Behaviour of Paramecia (after Jennings)

A, Paramecia gathering at a spot with a slightly acid reaction. B, Paramecia which have moved away from a spot with a slightly alkaline reaction. C, Rectilinear movement of Paramecia; the animal keeps within a slightly acid zone.

chemical phenomena from the biological standpoint than that of biological phenomena from the standpoint of chemistry. That type of study has already led to the great advancement of chemical science, and it is now known how an immense variety of reactions become adjusted to varying conditions, to the varying amounts of either reagent present, to the presence or absence of katalytic agents, and to changes of temperature.

The studies of both parties, those who seek chemical and mechanical explanations of biological phenomena and those who study adaptations to changes of conditions, are very useful at the present stage, for both help to diminish the barrier between living and non-living, the greatest bar which still prevents man from realizing the unity of Nature.

SOME RECENT RESEARCHES

MANIFESTATIONS OF LIFE.—Blackman has recently published researches on the subject of residual vitality, which connect the speculations already discussed with experimental fact. He found it possible to ascertain the order in which the activities characteristic of living substance ceased as death approached, the material chosen for observation being a leaf. The first quality to disappear is that of irritability, the quality which we have supposed to be the most complex and the last added in the evolution of life. Soon afterwards the organism ceases to be able to build up new material, to make the constructive predominate over the destructive processes—in other words, growth comes to an end; then assimilation, the taking in of carbon dioxide by the leaf in order to build up new material, ceases. The cells, no longer receiving new material, soon lose the power to retain their sap, which oozes out and evaporates, so that the leaf becomes flaccid, or, to speak technically, loses its turgidity; if this loss of turgidity approach completeness the leaf is irretrievably doomed, but there are still evidences of life for a time.

Finally the leaf ceases to breathe, to derive energy, that is, from the regular and controlled breaking down (oxidation) of the carbon compounds in its protoplasm to carbon dioxide and other waste products. This chemical exchange, the most universal of vital characters, is therefore the last to disappear. Thus the order of disappearance of the characteristics of life in Blackman's experiments is exactly the converse of the order of their evolution suggested by a priori arguments.

CHEMICAL SYNTHESIS.—Chemical research into the fundamental problem of life has progressed in recent years under the leadership of Fischer. He has built up more and more complex carbon compounds, producing ultimately the very large-moleculed albuminoids or proteids, without at any stage calling in the chemical assistance of a living organism or its products. This has broken down the old barrier between the organic and the inorganic realms, for it used to be supposed that proteids were exclusively produced by or through the working of living organisms.

Research is, none the less, very far from having attained the process of manufacture of protoplasm, for the protoplasm of each living organism is a complex mixture of proteids, a mixture also which is believed to vary comparatively little within the same species or race.

THE YEAST FERMENTS.—Buchner's researches on yeast have also helped to lessen the gap between living and non-living. He crushed yeast cells thoroughly by mixing them with coarse sand under pressure.

A yellow liquid free from cells was thus obtained, and it was found that this liquid retained the power of fermenting sugars for some time. It had previously been thought that this power was restricted to fully organized and living cells, but we must now suppose it to be an attribute of some very complex organic compound or compounds, which can exist a little time after the death of the cell. This complex body, zymase it is called, is evidently something nearly related to the living substance, and so it was a considerable achievement to separate it and follow its working apart from its possessor, the yeast plant.

CHAPTER II

THE CELL—TYPICAL MITOSIS (INDIRECT CELL DIVISION)

CELL ORGANIZATION

In the previous paragraphs the living organism has been discussed as if it were merely a mass of protoplasm, a mixture of proteid compounds; but no living organism is without far greater superadded complexities—complexities of structure and organization added to those of chemical composition.

THE NUCLEUS.—It has been stated that the typical unit of living substance is a CELL or energid, which consists essentially of protoplasm (fig. 163). That cell, however, has a definite organization made up of various parts, which must next be described. The two parts which typically stand out in contrast one with the other are the nucleus and the cytoplasm or general protoplasm, both made up of proteid molecules but of different composition. The nucleus, for example, contains phosphorus in some of its molecules, and is not digested by pepsin, which can attack and dissolve away ordinary protoplasm; it is therefore a more resistant, a more permanent, element of the cell than the remaining cytoplasm.

Balbani has some interesting experiments on a one-celled animal called *Stentor*, which is sufficiently large to allow an observer to cut out or divide the nucleus (fig. 164). He has found that many activities continue after excision of the nucleus; ingestion and even growth go on, and some irritability is still shown, but reproduction is no longer possible, and life is not long continued. It is therefore justifiable to

connect the nucleus more particularly with reproduction, and there is overwhelming evidence on this side in connection with the process of cell division to be discussed later on. From a number of other experiments it seems to follow that the nucleus is also connected with the building-up processes of the cell's life. Enucleate fragments retain the power of movement and other evidences of expenditure of energy far longer than their constructive powers.

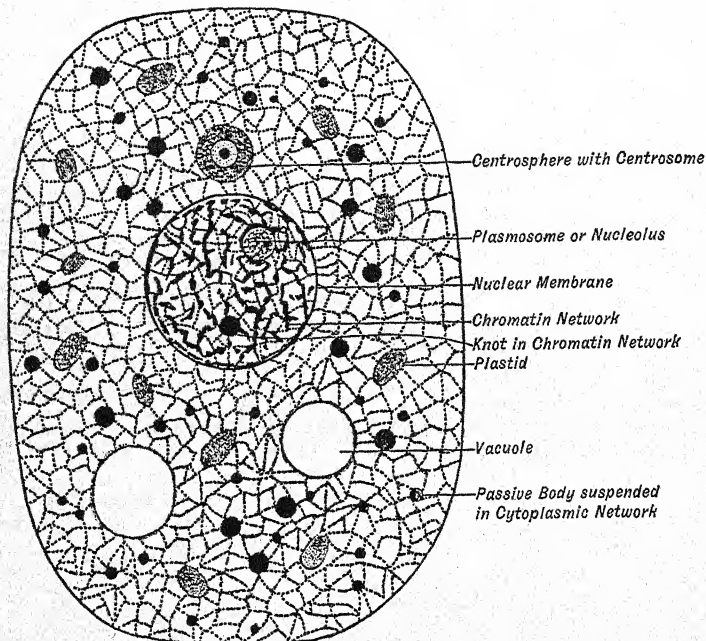


Fig. 163.—A Typical Cell (after Wilson)

THE CYTOPLASM.—The general protoplasm of the cell, the cytoplasm, is less condensed than the nucleus, it also takes up many staining reagents in smaller quantity. Many theories have been propounded as to its structure. Altmann supposed it to be made up of minute granules, several naturalists have held a theory of its fibrillar structure, while Bütschli thought of it as a foam (fig. 165). Staining reveals a kind of network structure, but it is not certain that this is not a post-mortem feature. Minute granules (microsomes) are very often present in the cytoplasm of a living cell. Bütschli's theory again has this in its favour, that its author was able to observe in artificial foams several of the movements of an amœba or a slime-fungus (*Myxomycete*). The foam theory is at any rate useful in that it enables us to imagine chemical reactions going

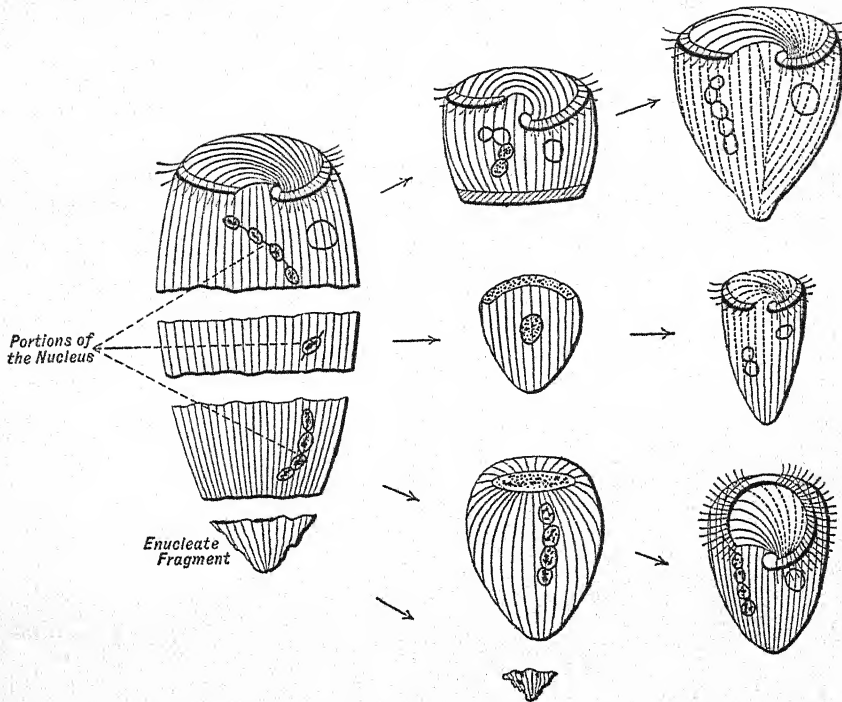


Fig. 164.—Regeneration in *Stentor*; a Protozoan with Elongated Macronucleus (after Balbiani)

on, perhaps semi-independently, in the many cavities of the foam, and thus to obtain some notion of that intricacy of complication of physico-chemical effects which forms so large a part of the mystery of life. A

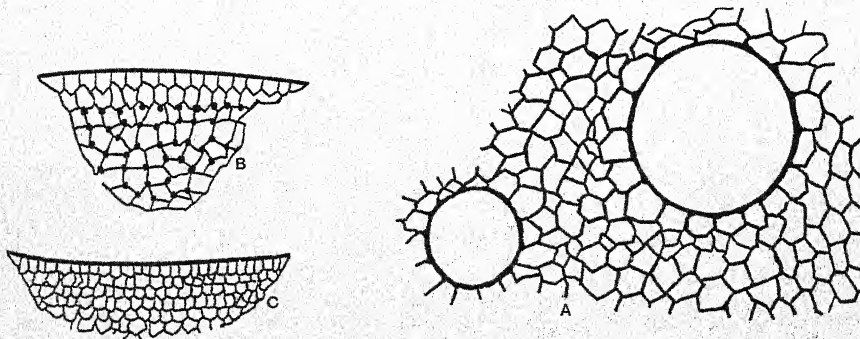


Fig. 165

A, Intra-capsular protoplasm in a Radiolarian. B, Protoplasm on the surface of a sea-urchin's egg. C, Artificial emulsion of olive oil, sodium chloride, and water (after Bütschli).

foam structure might also very easily give the effect of a network as a result of staining.

It is probable that most hypotheses of the structure of protoplasm

make some approach to the truth, but that structure is certainly not constant either from one cell to another, or from one time to another in the same cell, or even from one part of the cell to another. As life goes on, the cell's protoplasm often specializes in structure, and this is the case particularly with the cells of animal tissues such as striated muscle, where we find it finally transformed into contractile tissue with minutely delicate transverse striations.

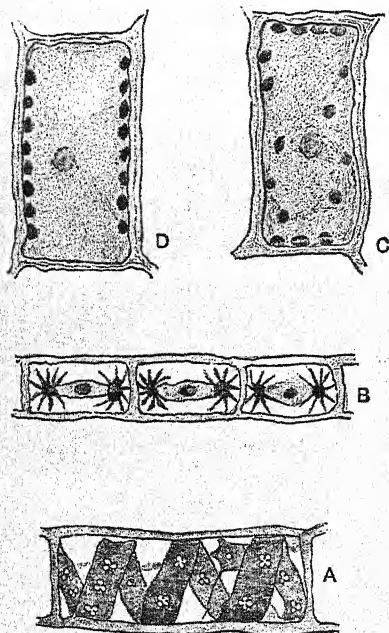


Fig. 166

A, Cell of *Spirogyra* with spiral chloroplast. B, Cells of *Zygnema*, each with two star-shaped chloroplasts. C, Cell of the upper palisade tissue of a leaf in the shade. D, The same in strong sunlight, showing the chloroplasts in rows on the side walls.

OTHER CELL ELEMENTS.—It has been said that the earliest organisms probably possessed some pigment which enabled them to absorb solar energy. In present-day organisms that pigment is typically green and contained in special bodies called chloroplasts, which lie in the cytoplasm. The dominant opinion is that these chloroplasts multiply by division and are not formed afresh from the cytoplasm; indeed it has been noticed that division sometimes takes place by means of a concentration of substance at opposite poles of the chloroplast. In many of the lower plants the cell may have one or two large chloroplasts or a band of green pigment; but in others, and in the higher land plants, these pigment bodies are usually very small and much more numerous. They can move through the cell's cytoplasm, and may often be found in a section of a leaf all in rows along the cell walls, parallel

to the direction of a strong incident light, so that the whole row save one are sheltered (fig. 166). It used to be thought by some workers that chlorophyll grains were really algæ living as messmates of the plant containing them, but this opinion is now quite discarded. Some plant pigment bodies of similar nature are yellow, and other bodies, also similar, are colourless, and go under the name of leucoplasts.

THE CELL WALL.—The cell wall, to which reference has been made, is characteristic of plant cells in general, though there are a few exceptions to the rule, and the most primitive of the one-celled organisms

are amongst these latter (fig. 167). It is therefore a plant specialization, and the discussion of it comes more naturally within the domain of botany than of general biology. The general opinion is that the protoplasm in contact with the wall of a plant cell is slightly hardened and

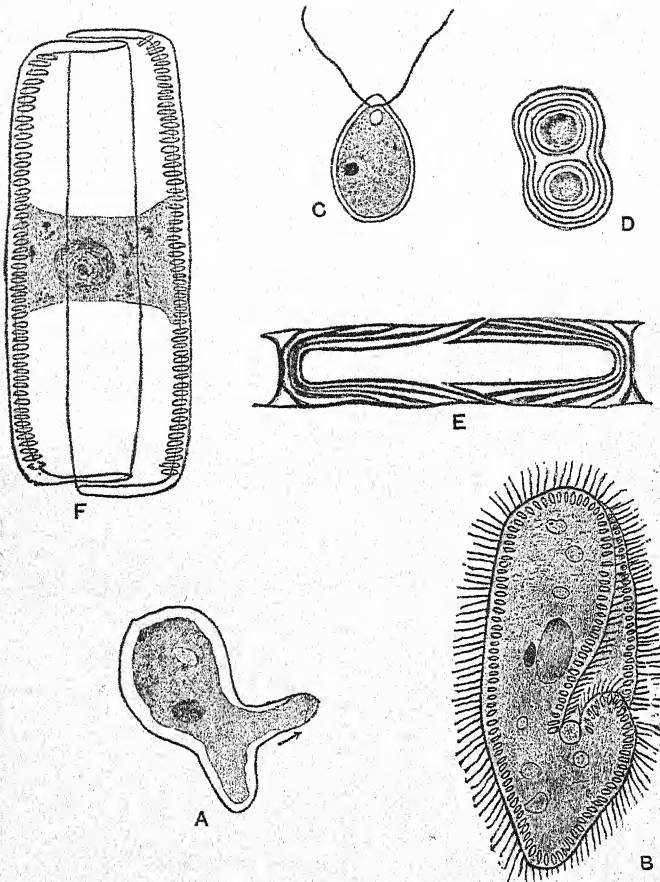


Fig. 167.—Cell Walls, Cell Membranes, &c.

A, *Amœba* with ectoplasm and endoplasm. B, *Paramecium* with ectoplasm covered by a protoplasmic membrane. C, *Chlamydomonas* with cellulose cell membrane. D, *Gleocapsa* (blue-green alga), with outer and inner zones of protoplasm and a protective coat of layers of gellerta (jelly). E, The cell wall of a *Conferva* (Algæ). F, Shell of a diatom.

specialized to form a membrane. A more or less similar membrane lines vacuoles or sap-filled cavities in the protoplasm, and it is the opinion of some naturalists that these vacuoles, in plants at least, arise by division of pre-existing vacuoles. This view is much more doubtful than in the case of chloroplasts mentioned above.

The protoplasmic membranes allow only certain substances in solution

to pass through them, while an ordinary plant cell wall of cellulose is permeable to all crystalloid bodies dissolved in water. A solution passing into the cell sap has to pass through the cell wall, through the protoplasmic membrane lining that wall, through the cytoplasm, and through the protoplasmic membrane lining the vacuole or sap cavity. If it is changed on its way through the cytoplasm or other parts, or in the vacuole, the latter never contains a concentrated solution of it, and more can pass in. The vacuole must then increase in size and press out the cell to its full extent. This is what occurs when the cell is turgid, as it

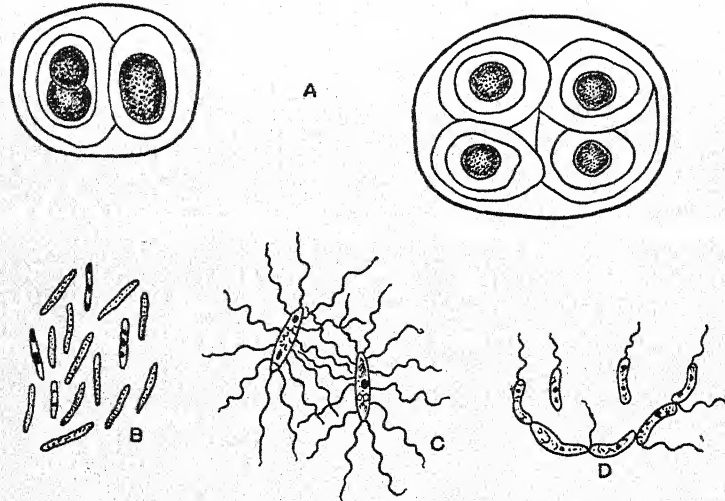


Fig. 168

A, Cells of *Gloeocapsa* (one of the *Cyanophyceæ*). B, *Bacillus* of tubercle. C, *Bacillus* of typhoid. D, *Bacillus* of cholera. Very highly magnified (after Fischer and others).

normally is in a state of health. The pressure within a plant cell has been found to rise even above 5 atmospheres, but the membranes just named resist the outward passage of water sufficiently to avert breakage.

GENERAL CONSIDERATIONS.—The discussion of the modifications of the vegetable cell wall and their meanings may be left to the botanical section. The evolution of the animal cell is touched upon in a later paragraph. As regards cell coverings, animals differ from plants in not possessing anything of the nature of a true cell wall. Among them the outermost zone of the protoplasm is specialized (fig. 167); in one-celled animals it may form a tougher zone (*Amœba*) or a protoplasmic membrane (*Infusoria*). The original evolution of the nucleus, chloroplasts, &c., is a very difficult problem, towards the solution of which very little has been done. A primitive group of plants, the *Cyanophyceæ*, or so-called

Blue-green Algæ, are interesting in this connection, for they seem to possess no nucleus, and their pigment is aggregated in an outer zone of the cytoplasm (fig. 168). Is this pigment zone a chloroplast, or one should rather say a chromoplast, in process of evolution, and is the central unpigmented zone an undifferentiated nucleus? These are questions which remain unanswered in spite of much discussion. The bacteria, again, are not known to possess nuclei, but they take up nuclear colouring reagents with great avidity, so the nuclear material (chromatin) may be scattered in granules through their substance. In *Tetramitus*, a simple one-celled organism, there is a central body around which the chromatin granules gather. In some other one-celled forms there is an indefinite mass of chromatin within a nuclear membrane. A few show chromatin in clumps. In the higher one-celled forms the nucleus is well developed but very various. The question of a nucleus in yeast cells has long been debated, probably in this case the nucleus is modified, and its substance runs in strands through a space or vacuole.

STRUCTURE OF THE NUCLEUS.—The nucleus stains differently from the cytoplasm, and can thus be made to stand out in contrast to the remainder of the cell when treated with colouring reagents. It is a spherical or ovoid body in ordinary cases, and when not in process of division is enclosed in a distinct nuclear membrane. With a high power of the microscope one can distinguish within the membrane (fig. 163)—

1. A network of nuclear material which stains strongly with hæmatoxylin or other nuclear stains. This material is called chromatin.
2. A foundation of material which stains much less and is usually called linin.
3. One or more minute bodies, nucleoli, which stain even more intensely than the chromatin. Some of these, better known as plasmosomes, appear to have a covering of chromatin around a particle of linin or cytoplasm, while others, known as karyosomes, are perhaps mere knots in the chromatin network.

CENTROSOMES.—In animal cells there lies near the nucleus, but just outside it, a minute body called the **CENTROSOME**, or there may be a pair of centrosomes in contact with one another. Around the centrosome there is usually a centrosphere, also very small (fig. 163), and from this centre fibrillæ radiate out in the cytoplasm. The centrosome is mentioned in connection with the nucleus rather than with the cytoplasm, because both are intimately concerned with the process of cell division.

The occurrence of centrosomes in plant cells has been much debated. Their existence in the cells of many of the lower plants may be taken as

definitely established, especially in the case of reproductive cells, but the growing opinion is that they are not found in the highest plants. They have been found in a number of one-celled organisms, but in such forms they are usually within the nucleus, thus strengthening the grounds for the view that the centrosome represents a special differentiation of nuclear rather than of cytoplasmic material.

NUCLEAR DIVISION

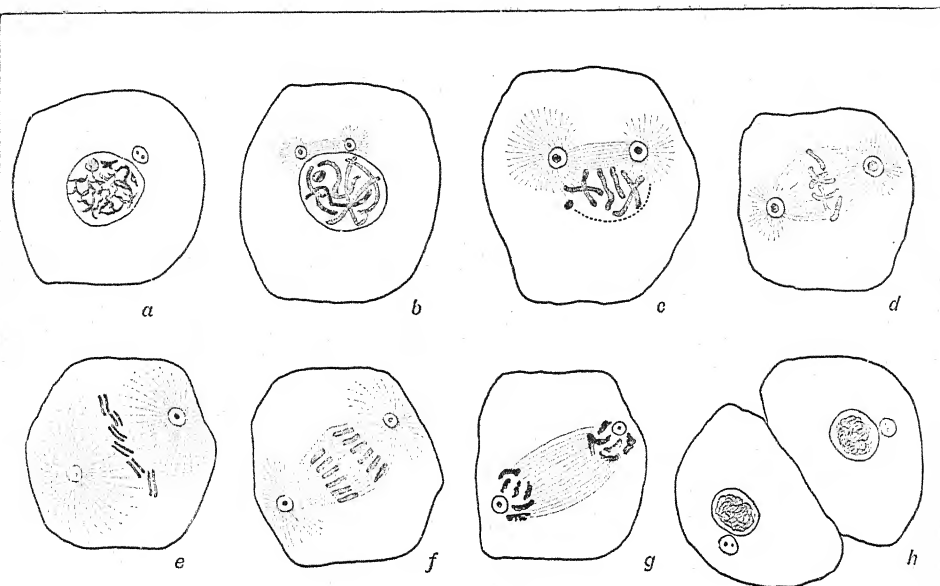
DIRECT NUCLEAR DIVISION.—The interest of the parts of the nucleus comes out more especially in connection with cell division, of which nuclear division is a necessary concomitant. There are various types of nuclear division, of which the direct and the indirect types stand out in special contrast to one another. Direct division is effected by a simple constriction of the nucleus in its equatorial plane, the network of chromatin being divided while the nucleolus (if one is present) splits and half goes to each daughter nucleus. It used to be supposed that this method of division was the primitive one, but it occurs only in very special cases. It characterizes some forms of glandular tissue, some cells forming transitory coverings of the reproductive tissue, &c., some diseased growths, and generally structures of only temporary existence or importance.

INDIRECT NUCLEAR DIVISION OR MITOSIS.—This is characteristic of most living organisms. As traced in multicellular plants and animals, it is a most complex process, which is evidently the result of long specialization, but the few observations it has been found possible to make on one-celled forms show that the evolution of this process may become a very important field of research.

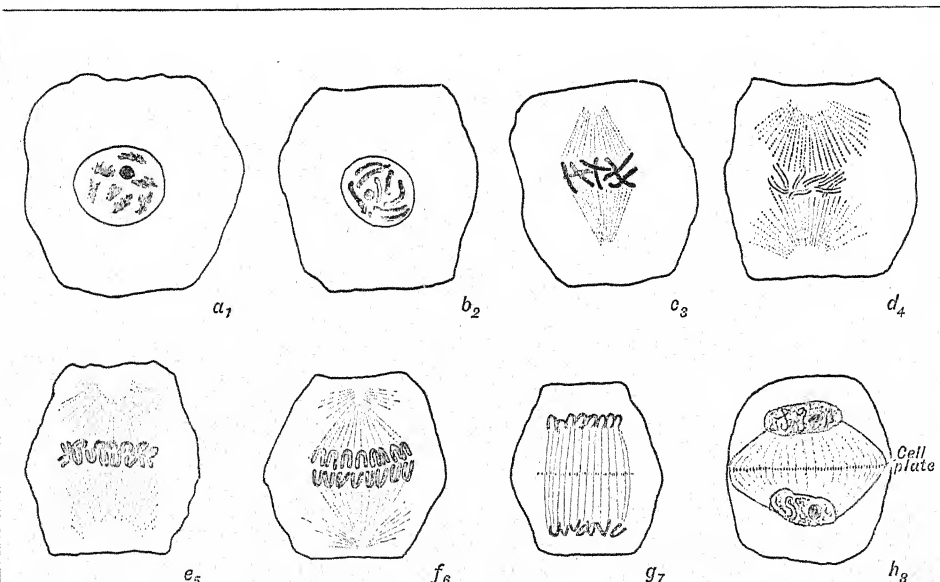
The process differs in detail in different forms, but there is a marked similarity in all its stages for the ordinary cells of most animals. Indirect nuclear division in plant cells differs in certain points from the same process in animal cells, but most higher plants exhibit marked resemblances to one another in this respect. The main outlines, further, are so much alike for both plant and animal cells that the one name of MITOSIS has been introduced to designate the process wherever it occurs. An older name is karyokinesis.

NORMAL MITOSIS: FIRST STAGE.—Normal mitosis in an animal cell begins with the following changes in the nucleus about to divide (see Plate).

1. The chromatin network is concentrated into one or a few long threads which gain in staining power.



NORMAL MITOSIS IN AN ANIMAL CELL



NORMAL MITOSIS IN A PLANT CELL (EMBRYONIC)

NORMAL NUCLEAR DIVISION IN ANIMALS AND PLANTS

ANIMAL CELL.—*a*, Early stage of preparation for division. *b*, Centrospheres separating, chromosomes formed. *c*, Spindle figure formed, nucleolus being ejected. *d*, Equatorial plate of chromosomes. *e*, Splitting of chromosomes. *f*, Daughter chromosomes diverging. *g*, Construction of daughter nuclei. *h*, Division completed, centrosomes have divided in preparation for the next division.

PLANT CELL.—*a*₁, Early stage of preparation for division. *b*₂, Chromosomes formed, nucleolus not yet ejected. *c*₃, Chromosomes approaching equator of spindle. *d*₄, Splitting of the chromosomes. *e*₅, Eight U-shaped daughter chromosomes. *f*₆, Daughter chromosomes diverging. *g*₇, Daughter chromosomes at the poles of the spindle. *h*₈, Daughter nuclei formed, cell plate developing.

2. The centrosome divides into two.
3. The nuclear membrane disappears.
4. The nucleolus is pushed out into the cytoplasm, and ultimately disappears. There is, however, an increasing probability that it really passes on its own substance to the chromatin threads as they form (1 above).

The two daughter centrosomes then move apart, and there appears between them a set of fibrillæ arranged like lines of longitude on a globe map of the world. This set of fibrillæ form what is called the achromatic spindle figure, achromatic because it does not arise from the chromatin. It is, perhaps, not of much consequence to enquire whether it arises from the nucleus or the cytoplasm; it is evidently a further development of the radiating lines which normally diverge from the centrosome.

Meanwhile the chromatin thread or threads have broken up into units which stain still more intensely. These are the much-discussed chromosomes, and they may be rodlike, V-shaped, ring-shaped, or even spherical. Minute investigation shows that they are made up of granules or platelets embedded in a mass of the "linin" of the nucleus. The number of chromosomes which appear in this way in the ordinary nuclear mitoses of any particular type is constant for that type, and, for reasons which will transpire later, that number is usually even.

NORMAL MITOSIS: SECOND STAGE.—Once formed, the chromosomes set themselves across the equator of the spindle, and the crucial stage of the process of mitosis is then reached. This crucial stage is the longitudinal splitting of each chromosome, a splitting which involves the splitting of each granule or platelet in the chromosome. If there were four chromosomes before, there will now be eight, four for each daughter nucleus.

NORMAL MITOSIS: THIRD STAGE.—The daughter chromosomes now set themselves along the threads of the achromatic spindle, and can be followed till they reach the ends of the threads at the poles of the spindle. As they congregate together their regular shape is lost, each puts out processes at the sides which connect it with the others, and this goes on until the network condition is attained. Meanwhile—

1. Material is set aside to form the nucleolus.
2. The nuclear membrane is re-formed.
3. The centrosome, now in the cytoplasm outside the new nuclear membrane, often divides into two preparatory to the next nuclear division.

Whilst the later stages of nuclear division are going on, the cytoplasm divides by a constriction in the plane of the equator of the spindle.

THE CENTROSOME.—The exact order of events in mitosis varies from

type to type. The fact that the centrosome often divides long before the chromatin begins to be arranged for the process has led some workers to call the centrosome the dynamic centre of the cell, the cause of the stages which follow. Further work has shown that there are many cases in which the chromosomes may be practically formed before the centrosome divides, so such a view seems doubtful, and it is best not to describe one stage as the cause of another. Whatever other meaning they may have, the centrosomes at any rate serve as moorings for the ends of the fibrillæ of the spindle figure.

NUCLEAR DIVISION IN PLANTS.—The above account applies to the cells of animal tissues. In the higher plants there are characteristic differences due to the fact that the cell possesses a wall, and that there are no centrosomes (see Plate). The general history of the chromatin network and the chromosomes is the same for plants and animals, but the achromatic spindle is more strongly marked in the latter. In the former a cell plate is formed along the equator of that figure after the chromosomes have split and moved away, and this cell plate grows out to the cell wall, cellulose being secreted to form the division between the two daughter cells. In some cases, perhaps, the spindle is moored to the cell wall, and so this function of the centrosome is provided for.

In the lower plants with centrosomes the process approximates more closely to the animal type, save that the cell plate is important in many cases. The description of centrosomes in higher plants is generally held to be due to error of observation.

GENERAL CONSIDERATIONS ON MITOSIS.—Now that the facts of mitosis are well established and accurately described, science is diving down into the abstruse and yet vitally important problem of their physiological causes. There was at first a tendency to suspect that some of the features described were merely post mortem effects, but a great many stages have now been accurately followed in living cells, and it has also been found possible to stain *intra-vitam*, *i.e.* without killing the subject.

The marked similarity of mitosis in plants and animals is perhaps an indication that the main physiological facts, the mechanics of the process, are not relatively complex; but the subject is so difficult that very little progress has been made.

It has been shown that if a colloid be placed in a solution which is being electrolysed, it will take up and retain a charge, and then move through the solution towards one or other pole (Billitzer). These facts have tempted speculation as to the possible electrical changes that may

be involved in mitosis: the chromosomes have been supposed to carry charges, and after splitting they are supposed to repel one another.

Other speculations have been put forth, according to which the fibrillæ of the achromatic spindle would be contractile and draw up the chromosomes from the equator, but these are subjects for the research of the future.

NUCLEAR DIVISION IN ONE-CELLED FORMS.—It is probable that light on these problems will be forthcoming when more is known of the evolution of the mitotic process (fig. 169). It has already been said that the centrosomes of one-celled forms are within the nucleus, and it is also

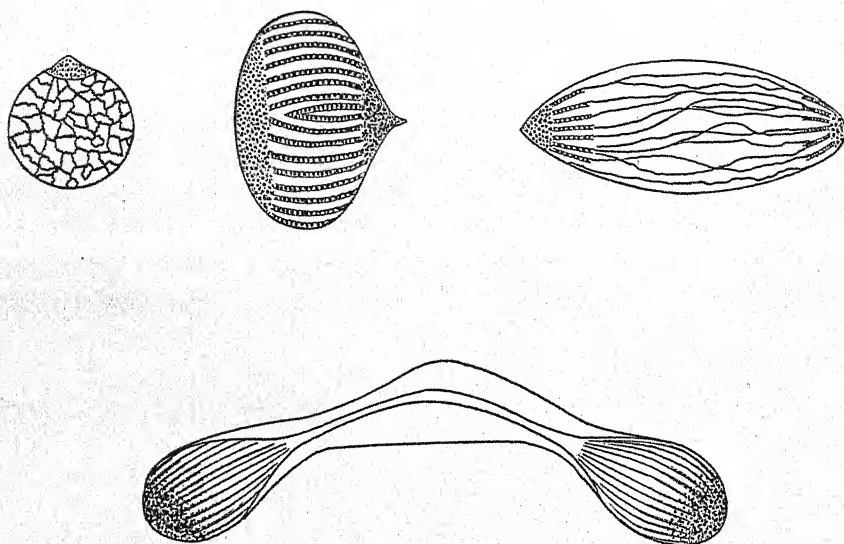


Fig. 169.—Stages in the Division of the Micronucleus in *Paramecium*, an Infusorian (after R. Hertwig)

true of many of them that the nuclear membrane does not disappear during the process of division. Many of them do not exhibit a well-developed spindle, and in many also the centrosome is not very well marked. The chromatin does often form long and distinct bands, but they are not so thick and concentrated as those of higher forms, and they do not split longitudinally in the same regular fashion. In fact, in these forms it is seen that the essential step is the division, not of the chromosomes, but of the granules of which they are composed. The spindle is usually feebly developed, so that this was probably the last of the leading features of the mitosis to appear in the course of evolution. The body which acts as a centrosome in unicellular forms is often that which is called the nucleolus by morphologists, and it is important not to attach any special meaning to the term nucleolus, which is used in so many different senses.

There are many divergent specializations in the mitoses of one-celled organisms, as though several variations had occurred in many directions, and one, the typical mitosis, had contributed to the survival and success of the forms which possessed it.

CHAPTER III

REDUCTION DIVISION—FERTILIZATION

REDUCTION DIVISION

INTRODUCTORY.—The process of nuclear division began to receive sustained attention about the year 1873, when a series of discoveries began to be announced. They gather around the names of Schneider, Bütschli, Fol, Strasburger, Flemming, Van Beneden, and Oskar Hertwig. The zoologists were at first ahead of the botanists, because of their greater experience in preserving delicate perishable tissues, and because Flemming was a great expert in the technique of preservation before he began his special researches on the cell. Later on zoological methods were applied to plant tissues, and discrepancies between the results of the two sets of workers were soon adjusted. In 1887 Van Beneden and Boveri discovered the centrosome, and thus gave a new impetus to cellular research. One of the difficulties in early years had been the fact that there were certain undoubted exceptions to the typical sequence of events described above. With increased observation it became known that these exceptional forms of mitosis occurred in the maturation of germ cells or some similar stage in both plants and animals. These exceptions show many points of agreement among themselves, and the process of nuclear division in them has been called Reduction Division. This is characteristic of the preliminary stages in the formation of germ cells, and is in many ways of quite unique importance for biological theory; but it is not yet thoroughly known, and its evolution is little understood.

Up to a certain stage the multiplication of cells in the ovary (female) or testis (male organ) of an animal is accompanied by typical mitosis of the nuclei. At this stage some of the cells grow and become oocytes (female cells) in the ovary, or spermatocytes (male cells) in the testis.

REDUCTION DIVISION: FIRST STAGE.—The nucleus of the male cell, when full grown and ready to divide, has a stock of chromatin, like that of every other nucleus about to divide, which is sufficient to supply

two daughter nuclei. As before, the chromatin becomes arranged in a long thread (spireme), and then the chromatin granules split. The long thread contracts and then usually splits into half that number of chromosomes which is normal for the nuclei of the ordinary cells of the animal to which it belongs (fig. 170). Each of these special chromosomes therefore contains twice as much chromatin as an ordinary new-formed chromosome. Its granules also have each split into two. These special chromosomes are thence called double chromosomes. In some animals a second splitting of the granules occurs to a greater or less extent; it is complete in the reproductive cells of the threadworm of the horse, so that here each double chromosome contains four rows of granules, and is thence known as a tetrad (fig. 170). Let us imagine a type of animal with, say, eight chromosomes in its ordinary dividing nuclei. Then the spermatocyte nucleus will have four double chromosomes, or, it may be, tetrads. In the first division of the spermatocyte each daughter nucleus gets one-half of each double chromosome. Now, since the spermatocyte nucleus has material enough to supply a

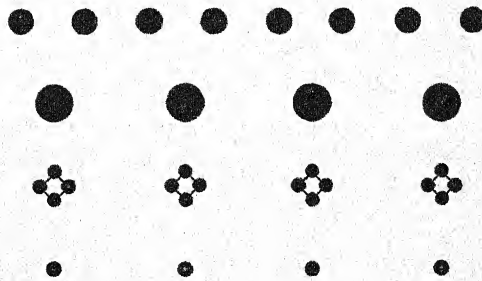


Fig. 170.—Diagram Illustrating the Phases in One Type of Reduction Division

normal amount to two daughter nuclei, it follows that this daughter nucleus gets as much chromatin as an ordinary daughter nucleus formed when any cell of the body might divide. But that chromatin is contained in four chromosomes, the halves of the four double chromosomes, instead of in eight as in the cells of the body in general.

REDUCTION DIVISION: SECOND STAGE.—These daughter cells divide again almost immediately, that is, before there has been time for increase of the chromatin by growth. Each of the four half-double-chromosomes divides so that the granddaughter nucleus has four quarter-double-chromosomes. It thus possesses only one-half of the amount of chromatin usually found in a new-formed cell of any organ of the animal to which it belongs. It is the nucleus of the sperm or ultimate male cell. The four quarter-double-chromosomes obviously contain split parts of all the original chromosomes, even of all the chromatin granules of the spermatocyte nucleus, a fact with most important bearings on the theory of heredity.

THE EGG CELL.—The development of the egg cell from the oocyte

is similar in principle, but the spermatocyte, dividing twice as above, forms four sperms (fig. 171). The oocyte forms four cells in much the same way, but three of them are minute and die almost at once, while

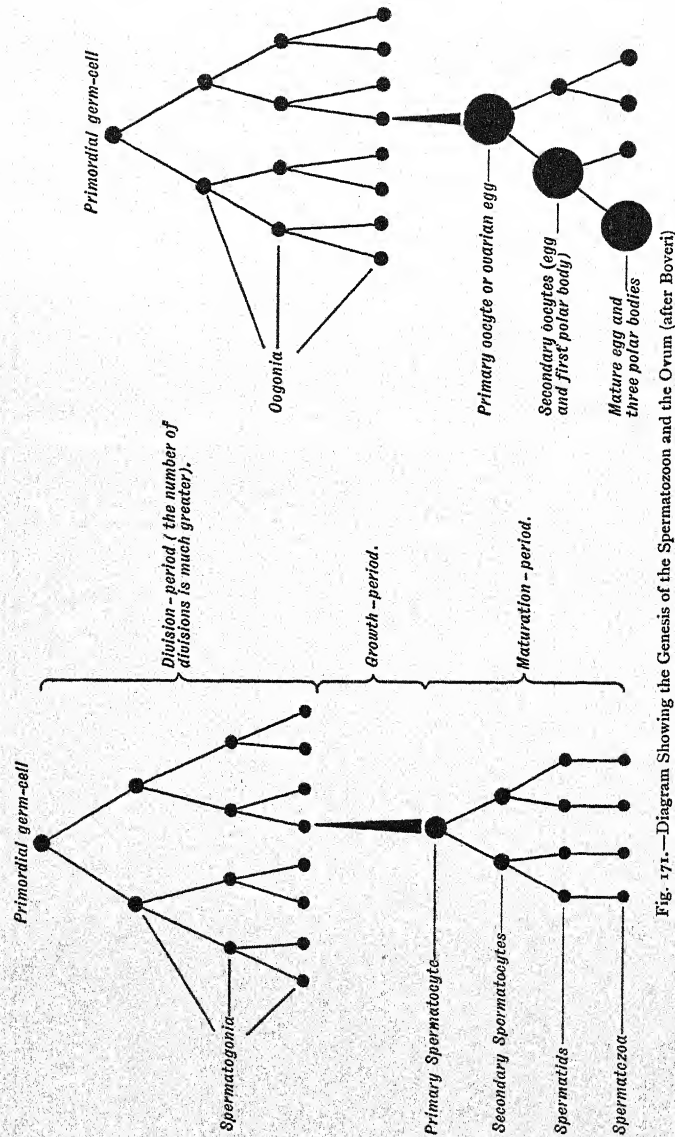


Fig. 171.—Diagram Showing the Genesis of the Spermatozoon and the Ovum (after Hovet)

the fourth retains nearly all the protoplasm and forms the egg cell (fig. 171). The division of the oocyte is thus first into a large cell and a small cell. Then the small cell, the first polar body, may or may not divide.

The large cell does divide again into the egg cell and the small second polar body. The nuclear history is the same as in the development of the sperm, so the egg cell has a nucleus with half the number of chromosomes (and half the quantity of chromatin) possessed by a normal nucleus of any ordinary cell of the same animal.

The discovery of these facts, mainly by the famous naturalists Oskar Hertwig and Theodore Boveri, has had far-reaching consequences in the study of biological theory, and reference will be made to them in the section under that title, when the newly discovered facts of the nuclear history of the sex cells in many insects will also be discussed.

CANCER RESEARCH.—A further interest has been given to this study by the discovery of stages remarkably like those occurring in reduction (heterotype) divisions among the cell divisions in cancerous growths. The modern work on this subject has been done mainly by Farmer and his coadjutors, but many observers think the resemblances are accidental, and point out that all sorts of abnormalities occur in nuclear divisions in diseased tissues. Still, the hypothesis that cancer is connected with the attempt of nuclei to divide as though they belonged to reproductive cells is, at any rate, a stimulus to minute observation and research, and so justifies its existence, whether it be ultimately proved or discarded.

REDUCTION DIVISION IN PLANTS.—The reproductive cells of plants undergo processes of division essentially similar to those noted above for animals, and the subject has been studied by many botanists, among whom perhaps Strasburger, Guignard, and Farmer stand out most prominently.

In a plant, reduction may occur long before the development of the actual germ cells, but whenever it takes place the chromatin of the nucleus usually gives rise to half the typical number of chromosomes; that is, the chromosomes are really double chromosomes. They are typically V-shaped, and, by splitting, form two Vs which remain attached one to another at the tips of the arms, thus forming a ring. There are therefore half as many rings as there are chromosomes in an ordinary typically-dividing nucleus.

The details of division into four cells differ in several points from those observed in animal cells, but as the essential result is the same, the botanical reader may be referred for them to Strasburger's article in *Progressus Rei Botanicae* (1907). The ovum of the plant, like the ovum of the animal, has half the number of chromosomes found in the ordinary dividing cells of the same type, and this is also true of the male nucleus within the pollen grain or other agent of sexual union.

One aspect of the preparation of the egg cell or oosphere of the highest

plants must be discussed, not only because it differs from anything found in animals, but also because peculiarly interesting discoveries have fairly recently been made in connection with it.

The cell in which the egg cell or oosphere will later arise is large, and has the name of the embryo sac. Its nucleus divides into two in the ordinary fashion, and these two daughter nuclei move to opposite ends of the embryo sac, but no cell wall forms between them. There each divides into four, and of the four in each case one moves back to the centre. Arrived there it fuses with its fellow and forms the "secondary nucleus of the embryo sac". The three others at one end are the oosphere with

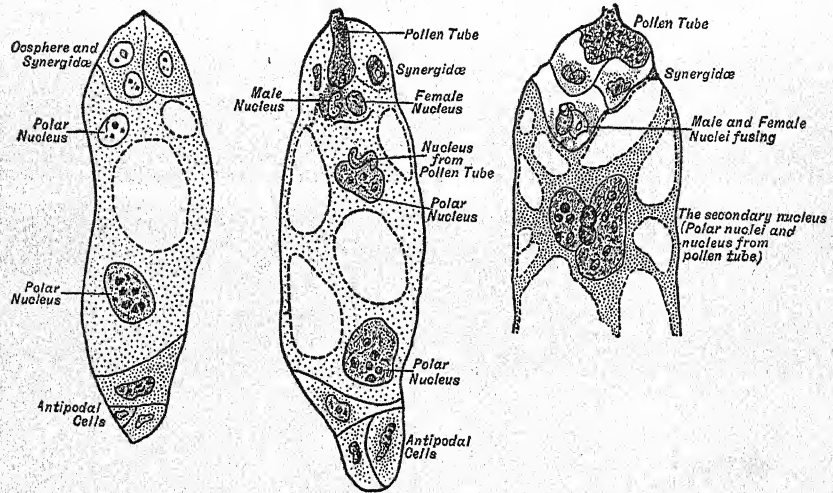


Fig. 172.—Fertilization in the Lily (from Guignard)

two usually sterile companions (the synergids), the three at the opposite end forming the antipodal cells (fig. 172). The special interest of the secondary nucleus of the embryo sac will be discussed a little later on.

GENERAL CONSIDERATIONS.—Of the evolution of the process of reduction division of the chromosomes very little is as yet known. Hertwig has, however, seen that in Infusorians (a group of one-celled animals), just before two animals conjugate or unite to form a new individual, the number of chromosomes in the dividing nucleus is less than (approximately half) that characteristic for the species.

To sum up, in spite of many mysteries we now know that in the preparation of the ultimate sexual cells the number of chromosomes is halved, and this helps us to understand better the process of fertilization, which has been the subject of so much research.

FERTILIZATION

WORK OF HERTWIG AND FOL.—It has been supposed for two hundred years that the essential feature of the sexual process is the union of a male element and a female element, but the first thorough description was given in 1875-80 by Hertwig and by Fol, who showed that the sperm of an animal enters the egg cell, and their nuclei fuse to form the first nucleus of the new organism which will arise from that cell. Each parent therefore contributes a half-share of nuclear material to the child, which thus begins with a normal supply in its original cell. It is true that the male nucleus is often very small when it enters the egg cell, but it enlarges before the union. Boveri and others have

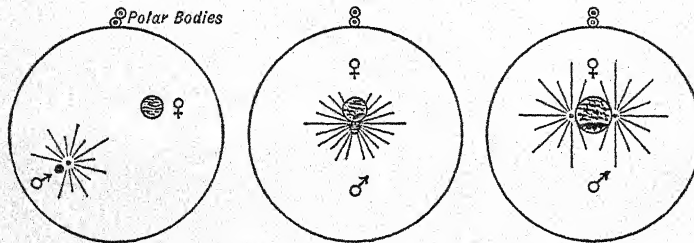


Fig. 173.—Diagram to Illustrate Fertilization

♀ = female. ♂ = male. A male nucleus enters the ovum and fuses with the female nucleus. The centrosome and its aster are contributed by the male. (After Wilson.)

added a very important observation as regards animals, for they find that the egg centrosome (female) disappears before or during fertilization, so that the centrosome accompanying the fusion nucleus is that which came in with the sperm (fig. 173).

WORK OF GUIGNARD.—In the case of flowering plants it has been observed by Guignard and others that two nuclei come into the embryo sac from the pollen grain. One of these is the male nucleus, which fuses with that of the oosphere. The other fuses typically with the previously mentioned secondary nucleus of the embryo sac, and the resultant nucleus gathers protoplasm around itself, and by continued division gives rise to a store of food (endosperm) for the young plant which will arise from the fertilized egg cell within it. This is obviously a special development, and if, as seems probable, endosperm develops only when this union has taken place, we may see in this a habit which has survived because it would prevent waste of energy in endosperm formation within unfertilized embryo sacs.

WORK OF MAUPAS.—Sexual reproduction, or at any rate the forma-

tion of the germ of a new generation by the fusion of two cells, is a very widespread phenomenon in both animal and vegetable kingdoms, and, especially in the latter, it occurs on very different lines in different groups, so much so that it has probably had an entirely different history in the different cases. This must mean that the possession of some kind of occasional nuclear fusion is a great advantage to any type. Maupas observed some Infusorians continuously for a long time, isolating one which multiplied repeatedly by simple division. He found that the descendants of the same ancestor could not fuse (conjugate) with one

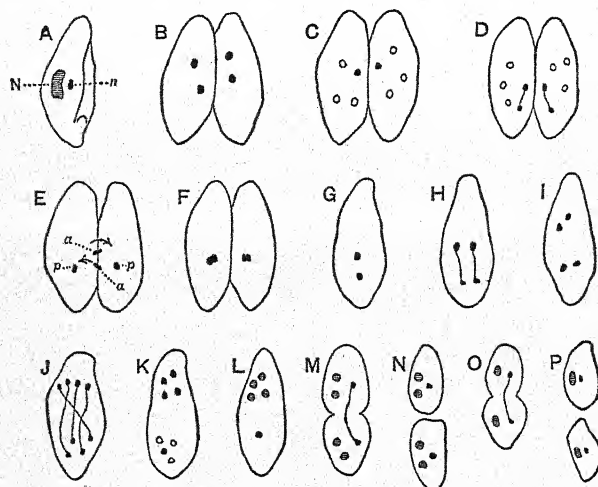


Fig. 174.—Temporary Conjugation of a Slipper Animalcule (*Paramecium caudatum*), diagrammatic and enlarged

A, A free individual: N, macronucleus; n, micronucleus. B-F, Stages in conjugation, showing successive divisions of micronuclei (macronuclei omitted), the fragments which disappear represented by clear circles—in E the active nucleus (a) of each individual is migrating towards the passive nucleus (p) of the other individual—in F each individual contains a compound nucleus. G-N, Changes in a conjugated individual leading to transverse fission, followed by (o, p) a further division in each half.

another, and that after a while they weakened and died off, but could be reinvigorated if some other members of the same species were mixed with them so that conjugation was possible.

CALKINS'S EXPERIMENTS.—Calkins has gone through these experiments and found it possible to obtain some hundreds of generations by simple division, but unless conjugation was made possible by the introduction of foreigners, the race always died out. On the basis of these and other observations has been raised the theory that conjugation (fig. 174) and sexual reproduction mean a rejuvenescence of the nucleus, and that this is the advantage which has led to the survival and further differentiation of the process. Other theories have been proposed, and

will have to be discussed in connection with the account of modern biological theory in a later section, when the history of the chromosomes and their meaning will also have to be brought into connection with the problems of heredity. Experiments like those of Maupas and Calkins must remain open to the objection that the final decay may be due to the fact that the conditions are abnormal in some unknown way, and Calkins has shown that by using various stimuli the organisms may be reinvigorated and the cessation of division almost indefinitely postponed. Critics dispute the length of this postponement.

WORK OF LOEB AND WILSON.—Loeb, Wilson, and others have also shown that in animals such as echinoderms, which usually reproduce in sexual fashion through an ovum fertilized by a sperm, it is possible to make an unfertilized ovum develop almost normally for a time by stimulating it with various salts, notably magnesium chloride.

CHAPTER IV

LOWEST FORMS OF LIFE—DIFFERENTIATION OF LABOUR AND ADAPTATION—POTENTIAL IMMORTALITY—LIFE-HISTORIES—PARASITISM AND SYMBIOSES.

Some account has now been given of the life of a cell, its multiplication by division, and its reproduction by conjugation or a more conspicuously sexual process, and this account should have made it clear how very highly specialized even the simpler one-celled organisms are as compared with the mass of colloid molecules discussed in the introduction. It is of interest to hint at a few stages of that specialization.

GENERAL SURVEY OF THE LOWEST FORMS OF LIFE

No one has any consistent conception of the primitive living organism as regards its specialization of structure and function, and, in fact, it is quite likely that life originated independently more than once. It is difficult, for example, to connect the structure and life of the bacteria (fig. 168) with those of other living things, and there are difficulties in attempting the like for the Blue-green Algæ (Cyanophyceæ). For the other living things we may go back so far as to suppose a mass of protoplasm with a nucleus, and a green pigment which enabled it to absorb

the energy of the red and infra-red rays of the solar spectrum. Whether the outer part of the protoplasm formed a membrane or not we may not decide. This organism probably moved by lengthening its body out. A membrane was an early specialization, as also was a flagellum or a pair of flagella, motile organs projecting through a pore in the protoplasmic membrane (fig. 175).

Thence some unicellular forms specialized by taking to feeding on

decaying matter or preying on their fellows. They thus obtained new protoplasm practically ready made, or at any rate the breaking up of this new food released energy so that they were no longer dependent on their green pigment. These unicellular organisms were the ancestors of the animal kingdom, and as this specialization proceeded the now useless chlorophyll or other pigment disappeared (fig. 175).

On the other hand, some unicellular organisms became more specialized for the absorption of solar energy used in building up new organic material from water, carbon dioxide, and various salts, and these were the ancestors of the plant kingdom. As specialization on these lines proceeded, power of autonomous locomotion became less important, and is almost non-existent among plants, except to a certain extent in the early stages of development of the lower plants.

Dimorpha radiata
(a colourless Flagellate)

Chromulina ovalis

Fig. 175.—Types of Flagellates

We therefore see that, apart from the Bacteria and Cyanophyceæ, it is possible to think of living organisms under three heads.

1. *Protista*.—Organisms which it is impossible to assign either to the plant kingdom or to the animal kingdom. These will be one-celled forms usually with nuclei, chlorophyll or other pigment, and power of movement.

2. *Animals*.—Including (a) protozoa or one-celled organisms which have the power of ingesting organic food, and are usually motile and without chlorophyll—and (b) many-celled animals.

3. *Plants*.—Including (a) protophyta or one-celled organisms with special adaptations for absorption of solar energy and building up of new organic material from simple chemical bodies diffusing into the organism—and (b) many-celled plants.

Plants and animals are obviously specializations of the Protista, and represent the result of the accentuation of alternative habits—in the one case that of absorbing organic matter, in the other that of absorbing solar energy and so on, as already described. Specializations of structure in connection with either habit could be of advantage to their possessors, which might thereby survive in the struggle for existence, and such specializations on many lines have led to the evolution of the multiform types of plant and animal life.

DIFFERENTIATION OF LABOUR—ADAPTATION

Among both plants and animals the habit of aggregation of the products of cell division appeared, and so we get the filament in plants and

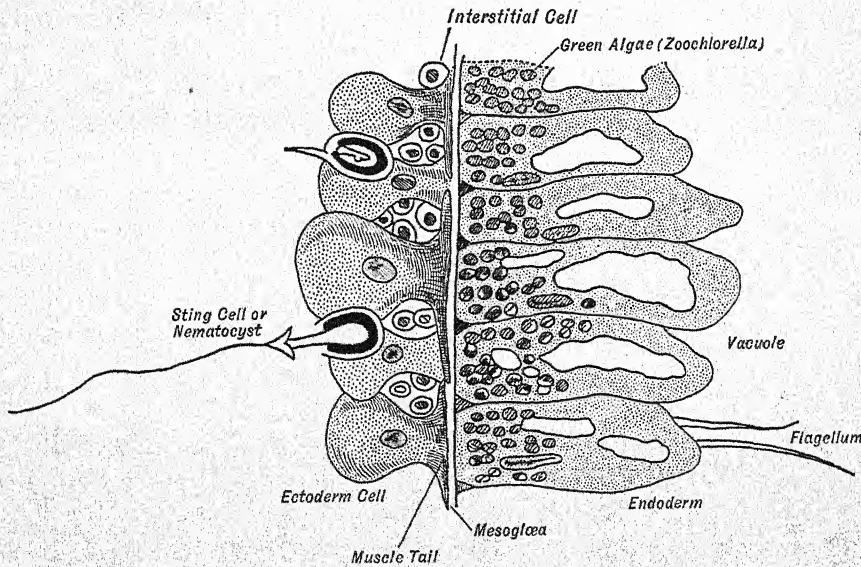


Fig. 176.—Section Through the Body Wall of *Hydra viridis* (slightly altered, after Marshall)

the colony of one-celled organisms among animals. In each case union was strength, and the habit survived. In plants, from the filament we proceed to the cushion or web or mass of filaments, and then some filaments become specialized for covering purposes, others for conducting food, and others for other purposes, including reproduction. Among

animals similarly we find some cells specialized to form a protective cover, others to do the work of ingestion, and so on (fig. 176). The primitive cell performed a large number of rather indefinite functions; the cell or filament-member of an aggregate has specialized to perform in a more definite fashion a smaller number of those functions, and the members of the aggregate are dependent on one another.

This is what is meant when naturalists speak of DIFFERENTIATION OF LABOUR. The various types of labour necessary for the maintenance of life have been sorted out, as it were, and are performed by different parts of the aggregate. Side by side with this has gone a progressive differentiation of structure. An organism with compacted covering cells, some of which were specially able to receive stimuli, and with ingesting cells protected and large and delicate, for example, would have advantages and thus survive. So, from one point of view, the study of plant and animal biology is essentially the study of progressive differentiation of function and structure, at first in the different parts of single cells, and later on in the different cells of an aggregate. As this differentiation proceeds in a cell aggregate, the parts of that aggregate naturally become more intimately associated one with another, and so the aggregate of cells becomes the multicellular plant or animal.

ADAPTATION.—Differentiation of function and its consequences are the outstanding facts in the history of plant and animal life, and the differentiations are typically adaptations to special circumstances. Thus the characters which best distinguish a limpet are those which fit it for a life on the shore rocks exposed to tidal wash, and the distinctive features of, say, a wood-sorrel plant are intimately connected with its life in woodland shades. The origins of this universal adaptation are the chief problems of biological theory.

POTENTIAL IMMORTALITY AND REPRODUCTION

As, apart from accidental deaths, the normal fate of a one-celled organism would seem to be division or conjugation, it has been held that these organisms are in a sense potentially immortal. With the differentiation of function and structure in multicellular animals and plants, it has come about that certain cells only are set apart for the work of reproduction, so these are the only ones which go on from generation to generation.

KINDS OF REPRODUCTION.—Reproduction may be effected in a number of ways which can be grouped under the following heads (fig. 177).

1. Reproduction by means of groups of cells which form buds, both

among plants and among the lower animals. Among plants we also find bulbs, corms, tubers, and ever so many other devices for the same purpose.

2. Reproduction by means of a single cell or SPORE. This type of reproduction is found in many one-celled organisms, and in both plants and the lower animals.

3. Reproduction by means of two cells which fuse. The cells which

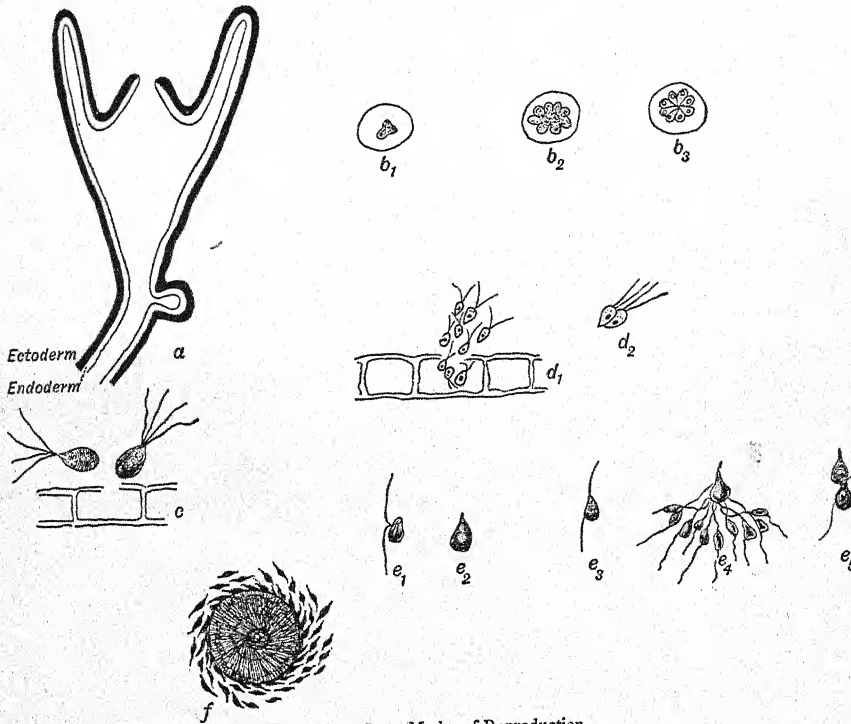


Fig. 177.—Some Modes of Reproduction

a, Budding, one form of reproduction found among hydroid polyps. *b*₁₋₃, Stages in spore development of the malarial parasite living within a red blood corpuscle of man. *c* and *d*, *Ulothrix* (a green alga); *c*, a cell which has just set free two zoospores; *d*₁, the liberation of gametes; *d*₂, conjugation of two similar gametes. *e*, Sexual reproduction in *Ectocarpus* (a brown alga); *e*₁ and *e*₂, young and mature female gamete; *e*₃, male gamete; *e*₄, males swarming around a female gamete; *e*₅, conjugation. *f*, Male cells (antherozoids) swarming around a passive nutritive female cell (oosphere) of *Fucus vesiculosus*.

fuse are called GAMETES, and their fusion is the essential item of the sexual process.

SPORES.—The formation of spores is often a means of retiring from unfavourable circumstances, the spores often resting for long periods and having special powers of resistance; bacterial spores, for example, must be heated above the boiling-point of water in order to kill them. There are many cases among one-celled organisms where a reproductive body may act as a spore or as a gamete, according to circumstances.

GAMETES.—The most primitive cases of fusion of gametes show the union of two similar ones. From this, especially among the seaweeds, we find all stages up to the fully differentiated sexual cells. One gamete has become the large passive egg-cell, the other the small active male element. The details of this evolution will be studied in the special zoological and botanical sections.

FERTILIZED EGG CELL.—The result of the sexual process is the fertilized egg cell with a nucleus formed by fusion of male and female elements, and in animals a centrosome derived from the male. From this cell arises a new organism resembling its parents but possessing an individuality of its own; this cell must therefore contain the germs of all the characters of the parent organisms, and the illumination of this mystery is one of the tasks of biological theory.

LIFE-HISTORIES

DEVELOPMENT AND DESCENTS.—The change of the fertilized egg cell into the fully developed organism is a gradual process effected stage by

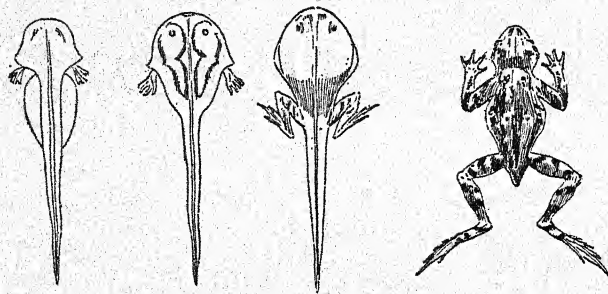


Fig. 178.—Different Stages in the Development of the Frog

stage, and in many instances among both plants and animals some of the stages recall to the observer's mind what were probably earlier stages in the evolution of the type to which the developing organism belongs. Examples of this fact are among the best-known phenomena of natural history (fig. 178); from a frog's egg arises a tadpole with many fishlike features, and naturalists are of opinion that the frogs and newts represent adaptations of originally fishlike types to a life less completely submersed. Similar phenomena could be mentioned for most groups of living organisms, but only one more will be given, and that from the plant kingdom. The gorse is a plant of the pea and clover tribe, but its branches and leaves have been modified into spines in correlation with its life on exposed places; the seedling of the gorse, however, has leaves which, though small,

still resemble the leaves of the other plants of its tribe (fig. 180). In spite of these facts it is none the less an exaggeration to say that the development of the individual parallels the evolution of the race; such a dogma is valid only as regards the very broadest outlines. The development of the individual is at the very most only a much-abbreviated and modified summary of the evolution of the race.

INDIRECT DEVELOPMENT—LARVÆ.—In many water-animals the eggs are shed just after or even before fertilization and without much special protection, so that the new individual is exposed to the stress of circumstances more or less throughout its development. This has led to many modifications in the course of that development. The ova of many worms,

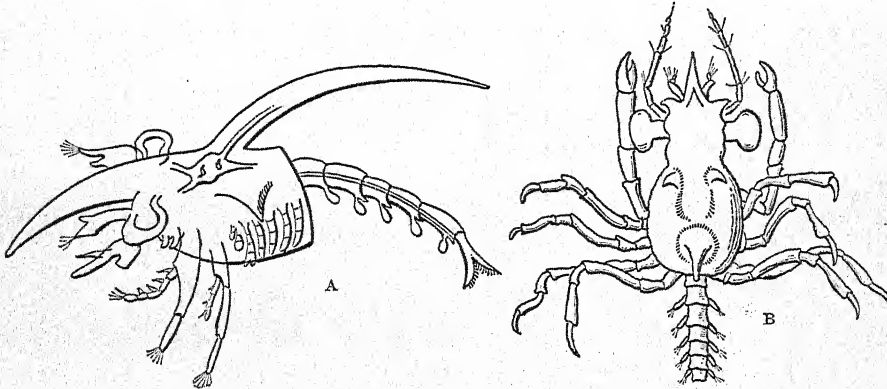


Fig. 179

A, Zoea stage in development of a crab; B, Megalopa (later) stage in development of a crab (adapted, after Balfour).

for example, develop floating in the sea, and the early stages of the young animal have come to possess bands of hairlike organs (cilia) which enable them to keep from sinking and even to swim. The fry (fig. 179) of many crablike creatures (Crustacea) live floating in the water, and they also have special organs fitting them for this phase of their life; in fact, the young may be utterly unlike the adults, and they are then called *larvæ* (*larva* in the singular). Some types, such as barnacles, possess several larval stages, each with its own special characters.

ALTERNATION OF GENERATIONS.—The study of life-histories reveals another kind of interest. Allusion has been made to the contrast between sexual and asexual methods of reproduction. In some cases among the lower animals these two contrasted processes are confined to different phases or stages of the life-history. Jellyfishes, for example, reproduce sexually, shedding eggs and sperms out into the sea; they are swimming and floating forms. The fertilized egg in many cases, however, does not

develop into a jellyfish; it forms an animal which lives attached by its base, and gathers food by means of a crown of feelers around its mouth.

This attached animal—a hydroid it is called—forms buds which develop into others like it, and a number of hydroids live attached together, forming a *colony*. After a while the colony forms other buds, from which the jellyfish stage emerges (fig. 181B). We have therefore an alternation of an asexual hydroid with a sexual jellyfish or medusoid generation. Alternation of generations of a very different type occurs among many plants, notably the liverworts, mosses, ferns, and higher plants (fig. 181A). It can be best followed among the ferns, where the conspicuous plant reproduces by asexual spores formed, as is well known, beneath the leaves. The spore does not develop into a fern plant, but into a flat green patch,

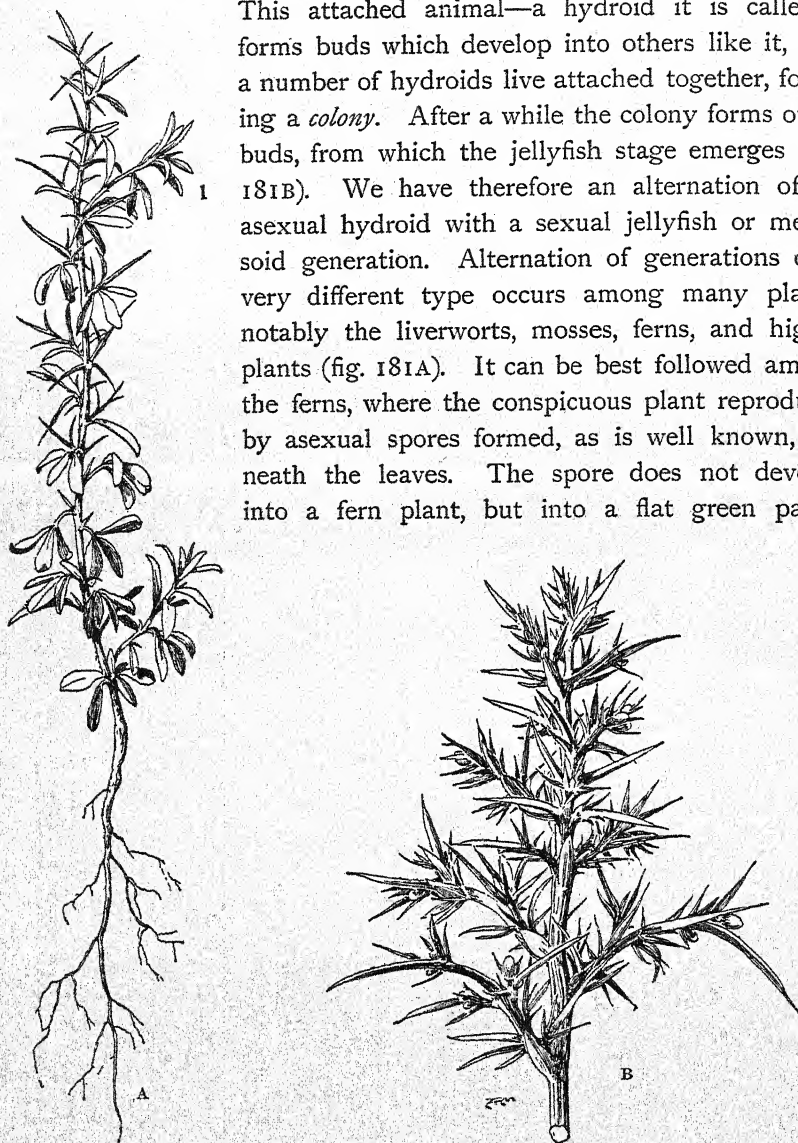


Fig. 180

A and B, Seedling (with compound leaves) and a shoot of the adult plant of the Gorse.

which shelters in the damp soil below the parent. This flat green organism, the prothallium, develops the sex organs, and from a fertilized egg cell arises once more the conspicuous fern plant. The details of this process of

alternation of generations belong to the province of botany, but the jelly-fishes and the ferns may be profitably contrasted as showing alternation with entirely different histories and distinct meanings. In the jellyfishes the free-swimming sexual stage provides for the wide distribution of the type, while the asexual stage has an easy method of multiplication valuable for the survival of the race. Among plants the sexual process of fertilization of a naked egg cell by a motile sperm is one essentially dependent on the presence of moisture. The ferns grow out well above the soil, and their leaves are far too dry to ensure the success

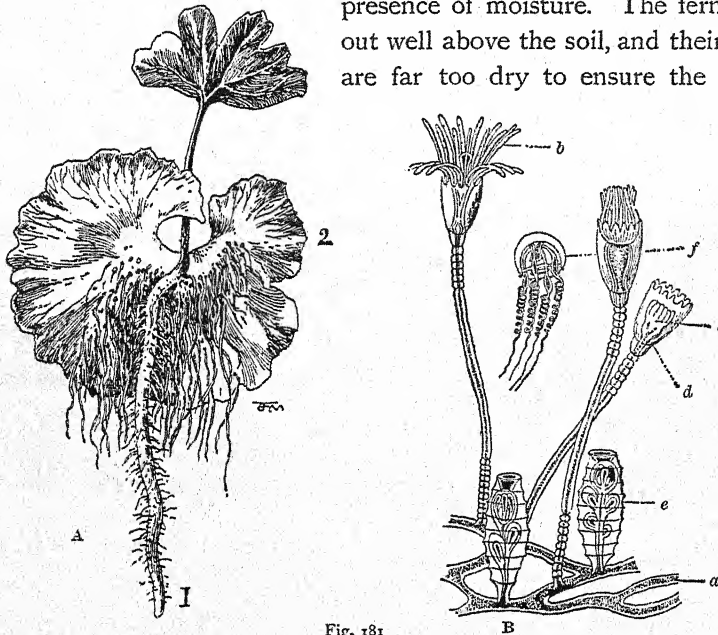


Fig. 181

A, The sexual stage or prothallium of *Adiantum Capillus-Veneris* (the maidenhair fern), showing attached to it a young fern plant (asexual stage) which has grown from one of its fertilized egg cells. B, Life-history of *Campanularia*. a, Branching base of fixed colony; b, expanded individual; c, individual retracted into its cup (d); e, case within which medusa buds are developing; f, a free-swimming medusa. The individuals of the fixed colony are asexual and multiply by budding. The free-swimming medusæ are sexual and from the fertilized egg arises a fixed individual.

of the process, so the old mode of life, in moisture, is retained for one stage of the life-history, the prothallium, and the sexual cells are formed and fuse in connection with that stage. The ultimate adaptation of this sex process to dry-land conditions among the flowering plants is one of the strangest and most wonderful chapters of botanical science.

PROTECTION AND CARE OF YOUNG.—Modifications of another kind arise in life-histories in connection with various arrangements for the better protection of the developing individual, especially among the highest plants and animals. The flowering plant forms a seed in which the new individual is enclosed for protection and which contains a store of food. The young

plant and its early history are very much modified in correlation with this arrangement, which has undoubtedly contributed more than anything else, except perhaps the successful adaptation of the sex process, to the world-wide triumph of its possessors. The protection of the young plant is peculiarly important for them, because they live on land, and a very young plant could not easily withstand exposure. Similarly, it is among the higher land animals that devices for the protection of developing offspring occur. The reptiles lay eggs protected by a tough shell. The birds not only do this, but also generally keep them warm in the nest. Among the mammals the young develop within the mother's body, so that the protection is far more complete in this group, and it is probably very largely because of these perfected arrangements for the care of young that birds and mammals have become such dominant types. As the young develop in such special circumstances, it is found that the events in the course of their development are much modified. The young bird or reptile while it lives within the egg has special membranes for its protection and for breathing air through the shell. These membranes are further developed in mammals for protection, and to secure nutriment from the mother's body.

HERMAPHRODITISM AND SEX DIVERGENCE.—Among both plants and animals the organs of the two sexes are sometimes in different individuals, and sometimes within the same individual. In plants the hermaphrodite condition, with male and female organs in the same individual, is the more common. Among animals it is rarer; it occurs in only one backboned animal, and where it is found among molluscs (land snails, &c.) it has apparently arisen by the new growth of male organs within creatures originally female. If the sexes are distinct, it is quite possible for divergences of life and structure to arise between them, and the study of zoology furnishes many illustrations of this. One need only think of the secondary differences between man and woman as examples. In some cases the two sexes are so different that naturalists originally referred them to distinct species, genera, or even groups.

PÆDOGENESIS.—Some species, especially of animals, show a life-history which has been shortened by the loss of its last phase. In such a case the crucial change is the early maturation of the sex products; when these are maturing and almost ready to be shed, the reproductive process absorbs all available energy, and further development stops. Such cases are known under the technical name of Pædogenesis, and occur occasionally among insects, in the Axolotl, an amphibian which rarely goes beyond the tadpole stage, and elsewhere.

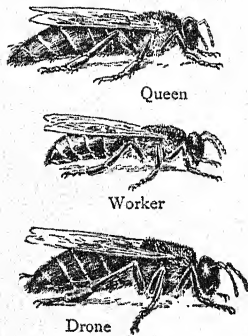


Fig. 182. — Queen, Worker, and Drone of the Hive Bee

is given to the fully sexual forms (fig. 182). In many cases, too, some of the members of an insect society, *e.g.* drones, develop from unfertilized eggs. In such cases it seems likely that the process of reduction division is shortened by omission of the second stage. Only the first polar body is formed, and the egg cell is therefore left with the normal amount of chromatin usually given to a daughter nucleus. This process of development from unfertilized eggs is called Parthenogenesis, and is also found in Aphides, Rotifers, and many of the lower animals.

COLONIES.—Among the members of an animal colony the development of individuals may be very much varied. Some

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Among social insects we find the reverse phenomenon in some members of the society; in some female bees, ants, &c., the reproductive organs do not develop at all. These are sterile, "worker" individuals, developed with a smaller food supply than

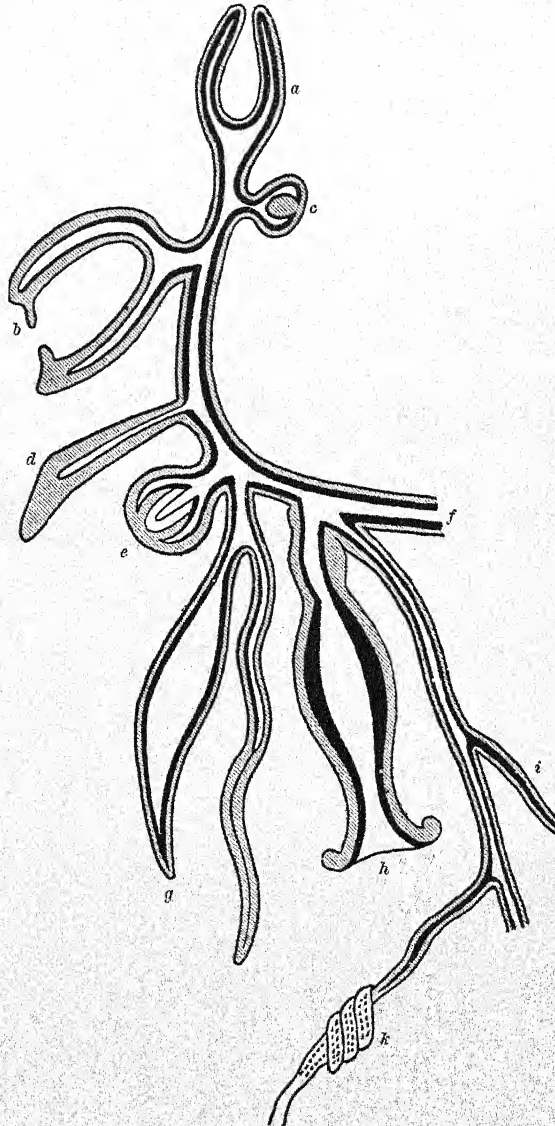


Fig. 183. — General Scheme of a Siphonophore Colony (after Claus)

a, Air sac. *b*, Swimming bell. *c*, Bud of swimming bell. *d*, Protecting individual. *e*, Sexual bud. *f*, Stem of colony. *g*, Tactile individual (with tentacle). *h*, Feeding individual. *i*, Tentacle. *k*, Battery of sting cells.

individuals may become the mouth or mouths for a large group, others may be mainly organs of movement, others again may be sense organs, and others reduced to mere reproductive sacs. In such cases the members of the colony are said to be polymorphic; they are no longer able to live for themselves, but form parts of the new living unit, the colony. Complete unification of individuals is, however, a complex change, especially the unification of their nervous systems, and one finds colonies with polymorphic individuals only among the lower animals with feebly developed sense organs and nerve tissue. The best examples are the members of the group of Siphonophores, where the colony includes swimming bells, tentacular individuals, and so on, each perhaps derived from a jellyfish-like individual (fig. 183).

PARASITISM AND SYMBIOSIS

EFFECT OF PARASITISM.—Probably the most far-reaching modifications of the life-histories of organisms occur in connection with the habit of parasitism. The influence of the parasite on the host may bring with it disease and death, or it may only cause certain abnormalities, of which insect galls may be quoted as an example. Here the parasite is an insect larva, and the gall is a result of the mixture of its excretions with the leaf sap of the host.

SYMBIOSIS.—In some cases it is not possible to speak of parasite and host in the ordinary sense, for each member of the partnership is useful to the other. Such unions are called cases of Symbiosis, and by far the best known is that of the Lichens, where, according to received opinion, the algal member of the partnership gets the advantage of shelter, fixation, and a greater amount of moisture than it could have alone, while the fungus takes much of the organic material manufactured by the alga. Fresh doubts have recently been cast on this view, and it may not completely represent the physiological situation. Another case is that of some tropical ferns, in the rhizomes of which are systems of galleries which give shelter to ants, while the excreta of the ants enrich the soil for the fern. A more important case is that of the bacteria which live in nodular swellings on the roots of plants belonging to the pea tribe, and which greatly benefit their host by manufacturing nitrates for it. Professor Bottomley's preparations of these bacteria in the spore stage have recently aroused much interest among cultivators, though it is not yet certain that mixing these preparations into the soil is sufficient to ensure inoculation of the roots.

GRADES OF PARASITISM.—The question of the influence of the parasitic habit on the parasite itself is of still greater biological interest. There are all grades in the development of parasitism. Some filamentous algæ can take advantage of organic matter in solution, but they usually manufacture their own food in the normal plant fashion. Then there are fungi which need decaying matter (Saprophytes), but still show evidences of their descent from algæ. Thence we go on again to the fungus or other plant parasite which usually depends on decaying matter, but may attack living plants and animals. The next step involves necessary dependence on a living host (true parasitism), which may be killed by the parasite, or only stimulated in special ways.

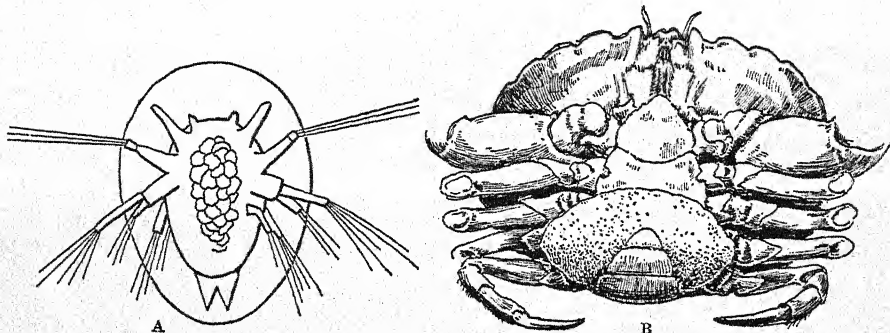


Fig. 184

A, Free-swimming (Nauplius) larva of a *Sacculina*, very highly magnified. B, An adult *Sacculina* living attached beneath the thorax of a crab and protected by the crab's abdomen.

So also amongst animals, the Hermit Crab uses an empty shell for shelter, but gets its own living. The Pea Crab shelters within the Mussel, and takes advantage of that animal's feeding arrangements, but still does a good many things for itself. Many other Crustaceans (Fish Lice, &c.) fix themselves to the skin or gills of their victims and feed on their blood. Some penetrate into their host, and ultimately we reach the case of *Sacculina*, which bores into a crab's abdomen, develops a root system within that victim's body, and forms an egg sac on its surface (fig. 184).

One of the dangers of the parasitic habit is that the young survive only if they find a suitable host, so the chances against that survival are often almost overwhelming. It has thus come about that those parasites have survived in which vast multitudes of reproductive cells are produced, and energy for this purpose is made available by the disappearance of the now useless sense organs and other structures accompanying independent life. Speaking generally, parasites have lost structural differentiations which do not bear upon the process of reproduction of their kind, or on

the work of finding a host. Sacculina, for example, retains the typical larval stages during which the animal lives freely and may find a suitable host; but in the adult stage it is merely an egg sac with roots spreading in its victim's body.

The exaggeration of the reproductive function at the expense of everything else is well illustrated among parasitic plants by many moulds (fungi) and by a few flowering plants, notably by the tropical flower *Rafflesia* with its enormous flowers forcing their way out of the victim,

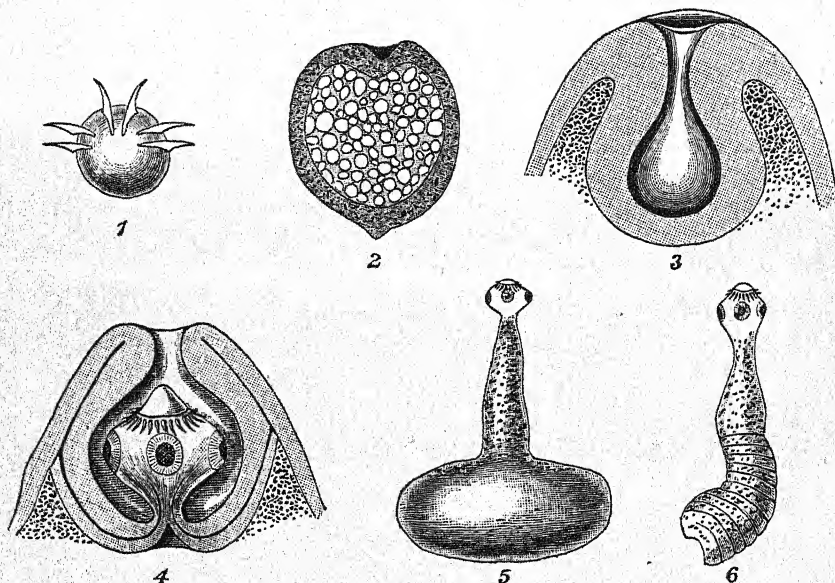


Fig. 185.—The Development of a Tapeworm

1, Six-spined (hexacanth) embryo. 2, Cyst (proscœlex) stage. 3, Early stage in the development of a scolex (one of many) on the surface of the cyst. 4, Later stage. 5, A scolex with the 'caudal vesicle' attached. 6, The young tapeworm, proglottides budded off behind the scolex.

and growing from what look like mere threads of protoplasm within the tissues of that victim.

LIFE-HISTORIES OF PARASITES.—A further complication is found in some cases, for example, among tapeworms, flukes, and other parasites in the animal kingdom, and among plant rusts. When an organism is dependent at one stage of its existence, there seems to be a tendency for that habit of dependence to spread to other stages. It is as if the larval stages of *Sacculina* were to become parasitic in their turn, each adapted to some special host.

A Tapeworm (*Tænia cœnurus*) passes one stage in the brain of the sheep (it causes staggers), and multiplies by budding new heads on the surface of a large cyst at this stage (fig. 185). The next stage is made

possible if the diseased brain is eaten by a dog. In the dog's intestine the head buds off a chain of individuals, each of which forms a vast number of ova and sperms, which unite and pass out with the dog's excreta. Lying on the grass, they may be eaten by a sheep, and then only the cycle completes itself.

The Liverfluke is also hermaphrodite, and forms enormous quantities of ova and sperms as it thrives in the sheep's liver. These ova and sperms unite and pass out of the sheep either before or after its death. The embryos, after some changes, need a Water Snail (*Lymnæus truncatulus*) for their further development. After a stage in this host they pass out and lie on grass, where sheep may chance to eat them.

It is obvious that the chances of survival of a fertilized egg-cell are very small when the life cycle has become so complex, but this is compensated for by the enormous number of ova produced, by their direct fertilization, since the animals are hermaphrodite and self-fertilizing, and by supplementary multiplication by budding, &c., at almost every stage and to an almost unlimited extent.

THE WAR AGAINST PARASITES.—To combat parasites which have two or more hosts, one possibility is the removal of one of these hosts. Unfortunately the Water Snail necessary to the Liverfluke is too inconspicuous to be thoroughly dealt with. Sheep farmers need dogs, but they sometimes guard against the danger of their dogs eating dead sheep with tapeworm infection by trying to destroy the sheep, or at least by placing them up in a tree where the dogs cannot get at them. It is said, however, that this latter habit can be traced back to an origin in folk-lore and superstition.

Plant parasites also sometimes have two or more hosts, notable examples being the rust fungi. The rust of corn has a spring stage on the Barberry, and laws of great severity have been passed against the planting or keeping of Barberry bushes in Norway and in some American States. As these laws have not been completely successful in extirpating the disease, perhaps our knowledge of the life of this rust fungus is not quite complete.

Some of the rusts are able to thrive on one host only; they have apparently specialized to one particular variety of protoplasm! Similarly, various mildew species differ in nothing that can be observed, save that one needs one special host and another another. Salmon has described these different species or races as *Biologic species* or *habit races*.

Habit races also occur, it is said, among the nitrate-manufacturing bacteria, and it is now being claimed that it is possible to gradually

accustom these bacteria to new hosts. If so, the value of these researches on the nitrate bacteria may become very great.

Attempts are made to fight plant parasites by spraying and by other methods; but the better way is to breed races which resist their particular foes, whether plant or animal, races which are "immune", and much research of this type is in progress.

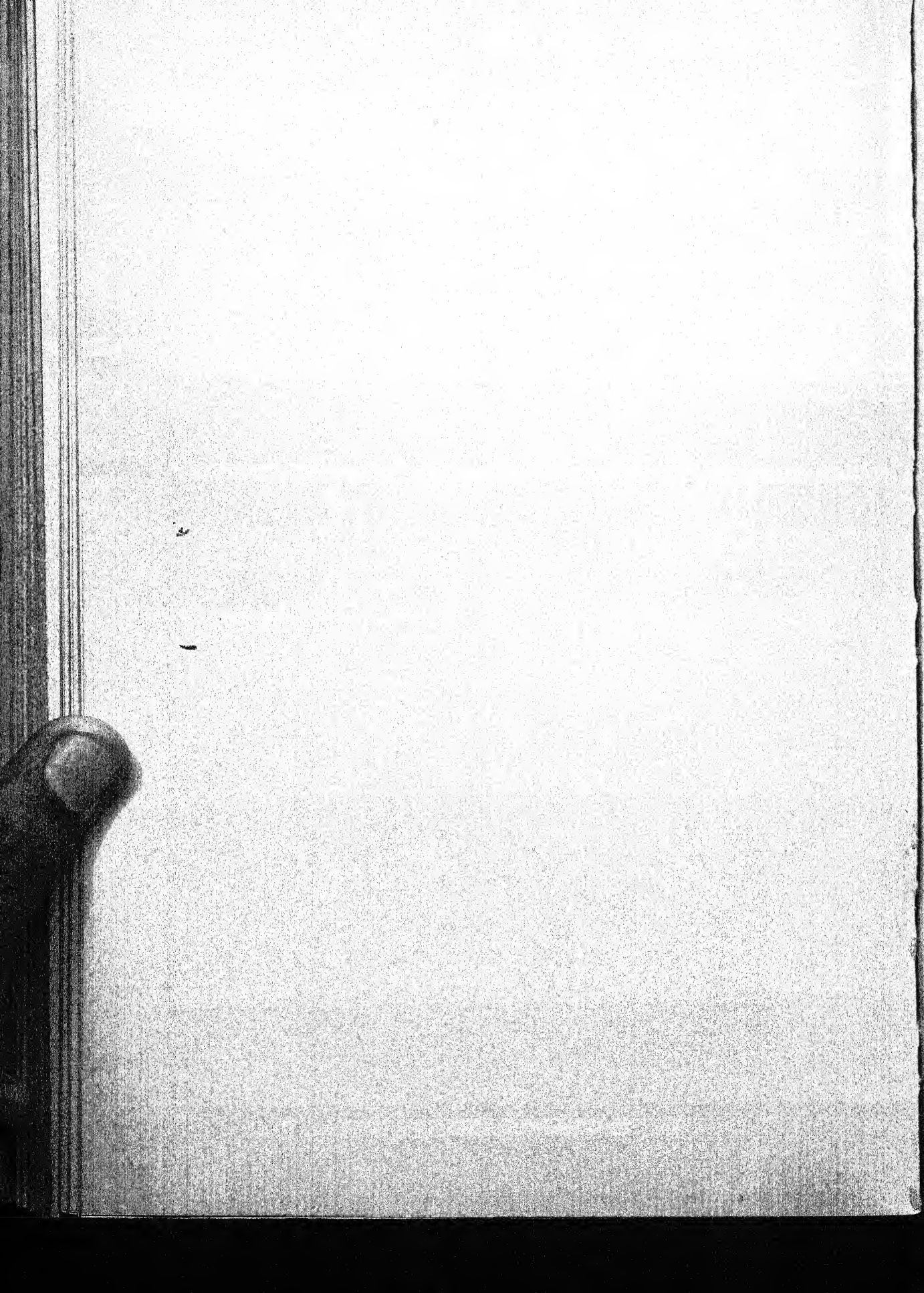
[For list of works recommended for further study, see end of section on "Philosophical Biology".]

BOTANY

BY

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BOTANY

CHAPTER I

INTRODUCTORY—ÆCOLOGICAL FACTORS

In modern Botany a desire for exact knowledge is not only evident in the fields of enquiry which border on the domain of the "Physical Sciences", but is also extending its influence more and more to those branches of the subject which until recently were considered hardly capable of quantitative treatment. To this fact may be in part attributed the growing interest shown by the general public in botanical work, and the increasing willingness on the part of practical men to apply the results of botanical research to agriculture and commerce. A brief review of the several departments which expansion and specialization have created within the science may serve to demonstrate the various points at which botany comes into contact with everyday life.

TAXONOMY (SYSTEMATIC BOTANY)

NATURE OF SUBJECT.—The aim of the taxonomist is to obtain all particulars concerning a plant which may help him in assigning it to its proper position in the scheme of vegetable life. The information required comprises: (*a*) the points of agreement between the plant under consideration and its presumptive allies; (*b*) its peculiar features; (*c*) its distribution in space and, when possible, also in time. It is evident that for purposes of reference and argument every kind of organism must be marked off in some definite and generally accepted way. To the uninitiated this may appear an easy matter, but a very slight acquaintance with the history of the naming and classifying of plants dispels this illusion.

LINNÆUS.—Systematic botany had been an active science in Europe for over two centuries before Carl von Linné (Linnaeus) put forward, in

his *Species Plantarum* (1753), what is known as the Binomial System of Nomenclature, that is to say, the principle that each form should be referred in the first instance to a group called a genus, and next defined by comparative marks or characters as a particular species of that genus. In this way every kind of living being known to Linnæus received two names: one, the SPECIFIC NAME, peculiar to itself, and another, the GENERIC NAME, common to all the species of the same genus. Thus the Sweet-scented Violet, variously *described* by other botanists as "*Viola martia purpurea flore simplice odoro*" (C. Bauhin), "*Viola nigra sive purpurea*" (Gerard), or "*Viola acaulis stolonifera foliis cordatis*" (Haller), is by Linnæus *named* "*Viola odorata*". The Heartsease, or Pansy, similarly becomes "*Viola tricolor*" in place of "*Viola tricolor arvensis*" (C. Bauhin), "*Viola tricolor sylvestris*" (Gerard; Parkinson) or "*Jacea tricolor sive Trinitatis flos*" (Haller; J. Bauhin). It is unnecessary here to consider the meaning which Linnæus attached to "species" or "genus". His principle of twofold names was soon generally accepted, and no better method has so far been devised. Since Linné's day, however, many changes in the names of species have unavoidably resulted from a variety of causes; the most formidable complication, apart from practical difficulties, has been the problem of the true conception of "species", a problem which remains in part unsolved even after the firm establishment by Darwin and Wallace of the unifying principle of affinity through common ancestry.

INDEX KEWENSIS.—In order to diminish the serious inconvenience which unfortunately arises out of the variability in the naming of even the most familiar wild and cultivated plants, the *Index Kewensis* was designed by Charles Darwin himself, carried out through his liberality by Sir Joseph Hooker and several collaborators, and is still being amplified in supplements prepared by the staff of the Royal Herbarium at Kew. This work records for every species of Flowering Plant: (1) the accepted name, with the author thereof; (2) the important synonyms, *i.e.* the different names given by other authors to the same species; and (3) the geographical distribution; it is indispensable in all work dealing with Flowering Plants.

The province of taxonomy was historically the first occupied, and in modern botany accurate taxonomy is just as essential as it was in Linné's time, although more particularly where economic plants are concerned its importance has by no means always been sufficiently appreciated.

MORPHOLOGY

Morphology comprises, in the first place, the study of externally recognizable structures in the individual plant; further, PLANT ANATOMY, or the study of internal construction, as far as this depends upon the arrangement of cells and tissues; and the minute analysis of cell structure or CYTOLOGY. Morphology often proceeds upon comparative lines, and attempts to link up different plants into series showing a gradual development or degeneration of particular structures (COMPARATIVE MORPHOLOGY).

PHYSIOLOGY

The plant physiologist looks upon an organism only as the vehicle of the inherent life. By experiment he endeavours to determine the proper functions of each organ, and his ideal aim is to reconstruct, mentally at least the living mechanism out of the portions separated by this analysis.

PLANT GEOGRAPHY

The most modest aim of Plant Geography is to determine the actual distribution of each species and to estimate its numerical strength in a given flora (FLORISTIC AND STATISTICAL PLANT GEOGRAPHY). Starting with such data, ECOLOGY examines the relations of plants to their environment; it is physiology transferred from the laboratory to the field, and its results must constantly be tested by experiments performed under controllable conditions.

PHYLOGENY OF PLANTS

Comparative Morphology naturally leads to the consideration of the evolution or PHYLOGENY of plants, more especially when extinct forms are compared with living species (PLANT PALÆONTOLOGY).

CORRELATION OF THE VARIOUS SECTIONS OF BOTANY

Physiology and Plant Geography are important aids to the study of evolution, while phylogeny and taxonomy evidently overlap to some extent; in fact, the sections of botanical science which have been distinguished above are very variously related to one another and to other sciences. Increased theoretical interest, or enhanced practical importance of a given division, from time to time leads to the separation of fresh independent lines of work. The rapid growth of cytology within the last

few years is a case in point. On the other hand, as the cytologist is bound to consider the structure of animal as well as of vegetable cells, this very case may also serve as an example of those borderland researches which help to keep the tendency to extreme specialization within bounds.

APPLIED BOTANY

In taxonomy the useful side is perhaps more in evidence than in any other branch of botany, while physiology promises the greatest ultimate benefit to man.

When a useful species of plant has been discovered and registered, it is usually thought that some improvement—from the human standpoint—of the natural material is possible. The alteration may be attempted in one of two ways. A predisposition in the plant may be encouraged by suitably changing the environment; or the constitution of the plant may be more directly attacked in an endeavour to create new races. In either case a sound knowledge of the relation of plants in general to their surroundings is needed.

ECOLOGICAL FACTORS

The environment—like the organization of the living being—cannot, to begin with, be apprehended as a whole, but must be analysed into a number of more or less conventionally defined “factors”.

For a terrestrial plant the chief factors are temperature, water supply, light, air, soil (inanimate factors), and the other plants or the animals with which it comes in contact (animate factors).

INANIMATE FACTORS—TEMPERATURE.—Among inanimate factors temperature on the whole stands first in order of geographical importance, on account of the “breadth” of its effects. It is well known, for instance, that some entire families of flowering plants are characteristic of hot climates, and others of cool and frigid regions. The range of temperature within which active plant life can exist is considerable, although it appears limited, when the extremes which seeds, spores, and other resting structures can endure are considered. One of the Scurvy-grasses (*Cochlearia fenestrata*) first comes into bloom in autumn, and continues flowering in the spring after a winter interval, during which temperatures of -46° C. are repeatedly encountered; and the lowest temperatures recorded on the globe (about -64° C.) occur in a part of Siberia which is covered with forests. On the other hand, the edible desert lichen (*Lecanora esculenta*) flourishes upon rock surfaces which are often heated

to 70° C., and the sand of a West African beach may be almost as hot (69° C.) and yet be overrun by creeping Morning Glory (*Ipomoea* sp.). In direct sunshine aerial plant organs may be many degrees above the temperature of the surrounding air, and similarly they may be much colder than the atmosphere on a clear, cool night. The general importance of this fact has long been neglected, although attention has been paid to it in special cases, such as that of succulent plants, in which exceptionally slight evaporation increases the heating effect of sunshine.

Obvious adaptations of structure to different levels of temperature are practically unknown; further, plants have not, as it were, seriously attacked the problem of maintaining a constant internal temperature. But the present state of knowledge regarding the exact relation of temperature to life is so unsatisfactory that we must fain be content to consider the temperature range of each plant a matter of "specific constitution".

INANIMATE FACTORS—WATER SUPPLY.—The relation of plants to their water supply can be discussed with more confidence.

Land plants are most conveniently grouped under three heads from the point of view of their water exchange. 1. **HYGROPHYTES** usually have foliage of large extent and delicate texture, and other special features tending to increase evaporation from the aerial organs (transpiration). This hygrophilous habit indicates favourable conditions of water supply, or an excess of factors favouring absorption over those increasing transpiration. 2. **XEROPHYTES** are in every way opposed to the first type; by reduction of shoot surface, encasement in a thick impervious skin, retention of a layer of air in contact with the transpiring organs, and other means, they contrive to keep down loss of water to a minimum. They are characteristic of dry places; but it is most important in this connection to note that the true test of dryness must be a *physiological* and not a physical one. A soil full of water may yet be physiologically dry because the work of roots is made difficult by conditions such as low temperature, poor ventilation, and a large content of soluble mineral salts or of humic compounds. Xerophilous species as a rule do not long survive exposure to moist surroundings; they are, in fact, definitely adapted to a dry environment and not merely indifferent to drought.

The degree of saturation of the atmosphere, since it is the agent most directly influencing the water output, is not less important than the amount of water available for absorption. Many plants, especially inhabitants of humid climates and seedlings, possess structures (hydathodes) enabling them to rid themselves of surplus water in liquid form when

transpiration is retarded. 3. TROPOPHYTES, such as our deciduous trees, are hygrophilous at one season, xerophilous at another. The alternation of reproductive and vegetative phases, and the details of reproduction and of processes connected therewith (dispersal, germination, &c.), are profoundly influenced by water, as will be shown later on. Finally, the œcology of water plants is totally different from that of the land flora.

INANIMATE FACTORS—LIGHT.—In its effects upon the structure of plants, light is second only to water supply. But œcologically it has a more limited action, because, in nature, differences of lighting are as a rule more local in their occurrence and application than are variations of humidity.

With the exception of fungi and most bacteria, almost every plant requires for its continued healthy existence a certain amount of illumination. Distinct from this general relation, the details of which are imperfectly understood, is the dependence of green plants upon sunlight as the source of the energy required in the process of carbon-dioxide assimilation (photosynthesis) which is carried on in the green cells and constitutes the entire intake of carbon, the chief chemical element of the plant body. Arrangements for making the most of the available light are far commoner than structures which prevent excessive illumination, and the frequent occurrence of a struggle for light where vegetation is dense cannot be gainsaid. But we do not at present possess a clue to the meaning of this craving for light exhibited by so many plants, nor can we always explain why other species thrive best in a poor light, as, for example, the *Aspidistras*, which flourish in an ordinary room largely on account of their frugality in this respect.

From the host of structures which have special relation to light we may here select for further discussion those organs which are believed by Haberlandt and others to serve for the perception of "one-sided" lighting. We are, in any case, certain that some such perception exists, and that it is the first step in the chain of reactions which we call "heliotropic" movement, *i.e.* the movement whereby an organ tries to regain its accustomed relation to light, when this has been disturbed. Papillæ, the structure of which suggested a comparison with tiny magnifying lenses, occurring on a number of heliotropic organs (especially leaves) were described by Haberlandt in 1905; quite recently experiment has proved that these little "lenses" do behave as light condensers, and that heliotropic movement of the organs possessing them ceases when the lenses are artificially put out of action.

The Cave-moss (*Schistostega osmundacea*) consists at one stage of its

existence almost solely of lens-shaped cells, which are, however, somewhat different in function from the structures just described. This moss grows in gloomy caves and rock clefts—for example, in the labyrinths formed by enormous erratic blocks in parts of the Thuringian Forest—and its lenses serve to concentrate the feeble light that reaches them upon the inner cell walls, against which the chlorophyll bodies are massed. A little of the light is reflected from these walls, and, passing on its way out again through the chlorophyll, produces a beautiful golden glimmer when a patch of the moss is viewed at a suitable angle.

INANIMATE FACTORS—AIR.—The atmosphere reacts upon the plant principally in two ways: first, as a whole, in the form of wind, and further, by virtue of its component gases, among which oxygen is the most important.

Wind, again, has a twofold influence; for beside the mechanical effects, which are beneficial in connection with the dispersal of spores and seeds and with other processes, its drying action, consisting in the rapid renewal of air around transpiring organs, is of great ecological importance.

Trees and shrubs growing on bleak coasts, and in other situations in which they are exposed to frequent gales, often appear “trimmed” on every side but on that which is turned away from the prevalent winds.

Kihlman describes how in Lapland junipers assume “topiary” shapes under the pruning action of the bitter wintry winds which are fatal to any twigs projecting above the snow-level; while the spruce maintains itself in the form of “mats” that rise only to the height of the surrounding felt of lichens and dwarf shrubs, but which reach quite a considerable size in the horizontal plane.

INANIMATE FACTORS—THE SOIL.—The ordinary terrestrial green plant absorbs all its food materials, with the exception of carbon dioxide, from the soil; hence the structure and composition of the soil must be of great ecological importance.

It is true that, geographically, the effect of the substratum is often local as compared with the influence of climate. But for this very reason, and also because to the cultivator the soil seems of all factors the one most readily capable of artificial modification, the applications of plant physiology to agriculture have been largely concerned with management of the soil.

Formerly much argument was expended in the endeavour to decide whether *either* the chemical character of the soil, *or* its physical structure was alone sufficient to account for the facts observed. It is now generally held that the two sets of conditions are intimately bound

up with one another, and that they must always be considered together. Moreover, we have come to recognize that an attempt to attribute the presence or absence of a given species *directly* to special characters of the soil must often fail, because in reality the relations between organism and substratum are far more complex and involve the factor of competition among different species. The discovery of a vast flora of microbes flourishing in the soil, and profoundly influencing its character, is largely responsible for this further adjustment of the point of view.

ANIMATE FACTORS.—The struggle for existence between individuals of the same species, and the rivalry between different species, are matters of great interest, and deserve more detailed physiological treatment than they have hitherto received. Here, however, the discussion must be limited to a few of the cases in which there is a direct and prolonged contact between two organisms.

CLIMBING PLANTS AND EPIPHYTES.—There is a gradual transition within certain groups of plants from climbers pure and simple, through forms which in early life raise themselves aloft to light and air by the aid of adjacent plants, but later sever their connection with the soil, to EPIPHYTES proper, which from the first grow attached to the surface of some larger plant, and in no way communicate with the ground.

Epiphytic plants exhibit many interesting adaptations, a few of which are described in the next chapter; they never penetrate into the living substance of the host, although the latter is frequently indirectly injured, or even destroyed, by such uninvited guests.

PARASITES.—True parasites, however, abound in the vegetable world; they range from the huge size of *Rafflesia Arnoldi* (the flower of which may weigh 15 lb.) to the exceedingly minute dimensions of bacteria, and are especially numerous in the class of fungi. It may be noted in passing that the study of parasites, and particularly of the conditions influencing infection and immunity, is of the highest practical importance; it furnishes many of the data upon which is founded the art of healing and preventing disease in man and in the species which are valuable to mankind.

SYMBIOSIS—LICHENS.—The intimate association of two organisms is termed SYMBIOSIS in those cases in which mutual benefits result from the partnership. The classic instance is provided by lichens, which in 1869 were proved by Schwendener to consist of algæ entangled in the meshes of a network of fungus filaments, and anchored by absorbing suckers (haustoria) proceeding from the latter. The cells of the lichen-forming algæ are often larger and of a more vigorous appearance when associated with the proper fungi than is the case when they grow in a

state of independence, as they may do; on the other hand, the fungus undoubtedly derives from the cells of its green companion a reliable and cheap supply of carbon, and indeed exhibits a certain ascendancy over the alga in the fact that it usually determines the outward shape of the compound structure.

MYCORHIZA.—Fungi sometimes occur closely associated with higher plants in the form of MYCORHIZA. This means that a fungus takes the place of root-hairs (absorbing organs) on the subterranean parts of the "host". There may be a more or less extensive invasion of the tissues by the fungus, but the fact that in this case the deep-seated portions of the intruder become disorganized and digested by the host proves that the relation is hardly one of parasitism on the part of the fungus, a view which is supported by other evidence.

The condition of SAPROPHYTISM, in which all food materials, including carbon, are absorbed from a non-living substratum, and most of them in the form of relatively complex compounds derived from decayed vegetable and animal matter (humus), is very frequently met with among fungi. Mycorhiza develops on the roots of many forest trees and other typical green plants, but is found more particularly in connection with plants which are themselves partially or entirely saprophytic; and Stahl's theory of mycorhiza suggests that certain higher plants have as it were discovered the remarkable power which fungi possess of exploiting the soil, and have instituted a friendly arrangement in the place of a competitive struggle.

ANIMALS IN RELATION TO PLANTS

The effect of animal life upon vegetation is to some extent destructive. Yet the interference of animals is often of use to plants and sometimes essential to their existence. Transference of pollen and dispersal of seeds by animal agency are cases in point; but consideration of these must be postponed for the present.

MYRMECOPHILY.—The symbiosis of plants with ants (Myrmecophily) is a fascinating subject, and one or two phases of this remarkable type of co-operation may be outlined here. Our first example concerns the Parasol or Leaf-cutting Ants (*Atta* spp.) of tropical America, and their mushroom beds. The suggestion, put forward by Belt, that the leaf pieces removed from various plants by foraging parties of these ants were used by them in their nests to grow a fungus crop was at first received with incredulity, but has been brilliantly confirmed by the observations

of Möller and others. Not only are the ants indeed "mushroom growers and eaters", but the common Leaf-cutter exclusively cultivates a single species of fungus (*Rozites gongylophora*); moreover, this fungus is unknown outside the nests, and produces special "Kohlrabi-clumps", swellings rich in sugar and protein, which constitute the special food of the growers.

This fungus is, in fact, entirely in the position of many an ordinary cultivated plant, except that it is raised by one of the most intelligent of social insects instead of by man.

Among the higher plants there are, especially in tropical America, but also in the Old World tropics, a number of forms which are described as myrmecophilous because they are usually inhabited by permanent colonies of ants. Snug cavities, either preformed (*Cecropia*, *Tococa*) or easily hollowed out by the ants in soft tissues (*Acacia sphærocephala*, the Bull's Horn Thorn), and rich and abundant food furnished by nectaries or by even more specialized glands (Bull's Horn Thorn), form the attraction in such cases. Some cecologists have considered this variety of symbiosis an adaptation of the plant against the attacks of the above-mentioned leaf cutters (in America) and against animal foes in general (in the Old World), thus regarding the settler ants as a kind of "police" maintained by the plant; but there are many objections to this view, one being the relatively feeble biting powers attributed to these ants by recent observers.

ANT GARDENS.—The most recently described case of ant-plant association is that of the curious "ant flower-gardens" (Ameisen-blumengärten), which are found upon trees in the Amazon valley (Brazil and Peru), in Guiana, and in Trinidad. Small ants of the genera *Camponotus* and *Azteca* build, upon trees, nests which are rounded masses of earth riddled with numerous passages and strengthened by the admixture of a papery material manufactured by the builders (fig. 186, upper nest). At an early stage in the history of such a nest seedlings begin to sprout from it on all sides (fig. 186, lower nest: the three-nerved leaves belong to the tree upon which the nests are built). These are tended by the ants, which continue to add fresh quantities of earth; they grow luxuriantly, and ultimately form a "hanging garden" of considerable size. By the abundant development of fibrous roots in the rich substratum the nest acquires greater coherence, while the dense roof of vegetation prevents damage by torrential rains. These ants are evidently at an advantage in the matter of economy of material and labour, choice of locality, and possibility of expansion, as compared with species which construct *barren* tree nests of similar fragile material, or lurk in cavities which impose

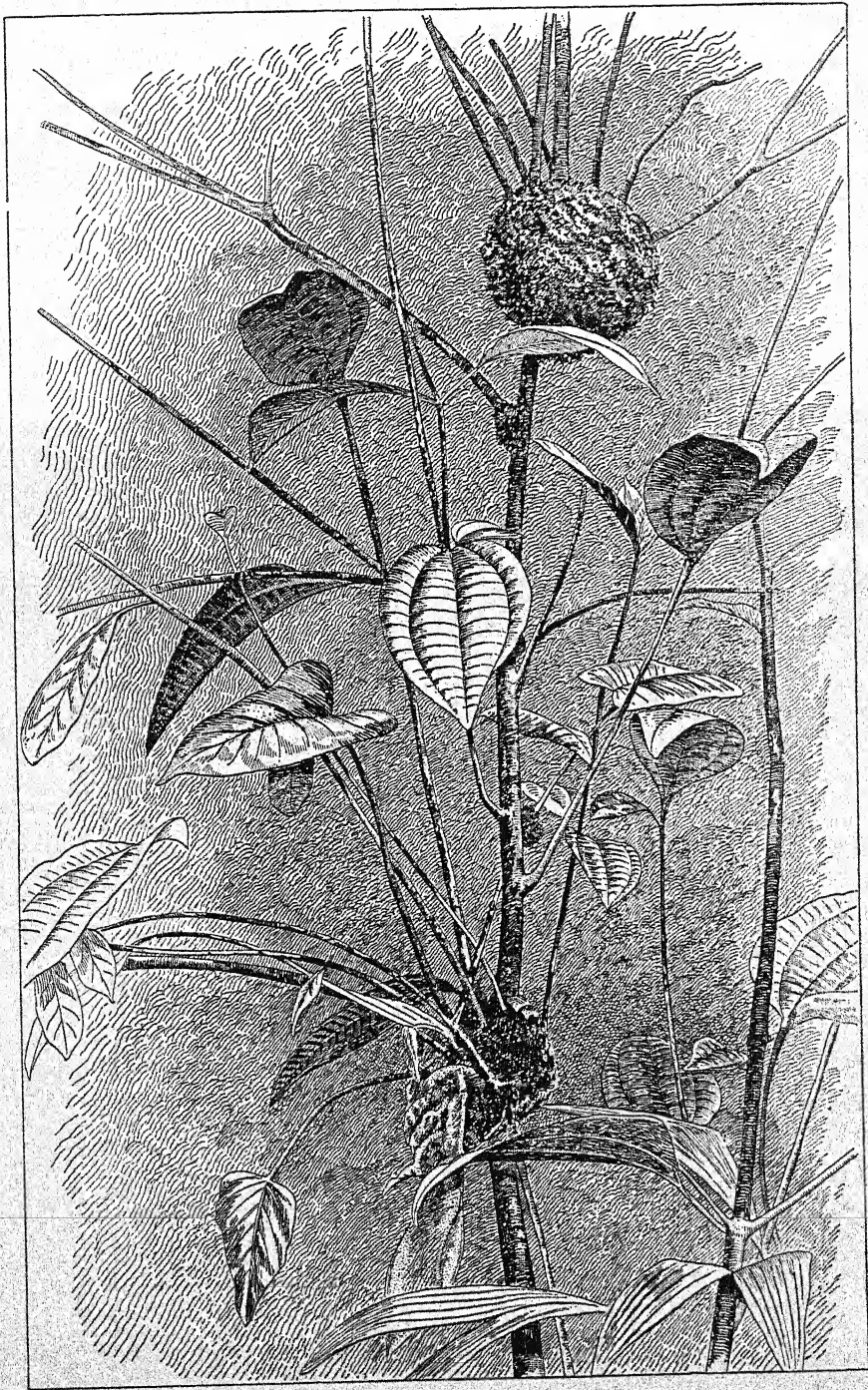


Fig. 186.—Ant Gardens

severe restrictions upon the size of the colony. On the other hand, the flora of the nests is quite peculiar to them, consisting of some fourteen species which do not occur elsewhere. The prevalent plants of Camponotus nests (*Anthurium Porteanum*, *Streptocalyx angustifolius*, *Codonanthe Uleana*) are nearly related to other species of the same genera which live as ordinary epiphytes. The Aztecas frequent the lower, shadier, and moister sites, and their gardens consist of more peculiar species. Growing in a rich, damp soil, these plants do not share the characteristics of genuine epiphytes, nor have the majority any close allies among true epiphytes. Several indeed occupy a very isolated taxonomic position, and have no relatives at all in the flora of the Amazon basin. All these ant epiphytes produce juicy fruits, which are collected and deliberately planted in their nests by the ants, and it is very unusual to find any plants outside this close corporation growing upon the nests.

COMPLEXITY OF THE LIVING WORLD—PRACTICAL IMPORTANCE OF THIS CONCEPTION

The phenomena of symbiosis, of which only a very few have been mentioned, afford some insight into the intricacy of structure and delicacy of adjustment which exists within even a limited sphere in the world of living organisms. Clearly a very slight interference with a single component may disturb the equilibrium of the whole system and produce far-reaching alterations, just as in the individual plant the delicate mechanism of the living substance may be so influenced by an apparently insignificant change in the environment that the final result is out of all proportion to the original cause.

It is necessary to bear this in mind in considering the influence of the human race upon vegetation. Man has, by long and painful groping in the dark, acquired so considerable a control over a certain number of species that the progress of science seems to promise him a much more extensive suzerainty over the plant world in the near future. There is, indeed, good reason for hoping that this promise may in great part be ultimately fulfilled. But failure to appreciate the complex nature of each plant and the manysidedness of its connection with the environment must at the least seriously impair the efficiency of scientific methods in agriculture and the related arts, and may even result in grave financial loss and consequent discrediting of botanical science as an instrument of utility.

PLAN OF FURTHER DISCUSSION

After this partial analysis of the environment, we pass on to consider some of the ecologically important types of natural vegetation, indicating, where this is possible, their dependence upon the various factors, and mentioning the principal economic species as occasion offers.

CHAPTER II

TYPES OF TERRESTRIAL VEGETATION—
TROPICAL ZONE

PRINCIPAL FORMATIONS.—Schimper, in his monumental *Plant Geography*, distinguishes three principal formations, which owe their chief characteristics and their general distribution to the influence of climate, namely Woodland, Grassland, and Desert. Where the climate is not exceedingly unfavourable to vegetation, trees and grass strive with one another for possession of the land. If all plant life is at a disadvantage, owing to hostile climatic conditions, this rivalry is obscured, and types from both the more fortunate formations eke out a scanty existence side by side in the desert.

REQUIREMENTS OF WOODLAND.—Woodland demands the presence of a permanent supply of water accessible to the extremities of the root system; but if this condition is fulfilled, the frequency of rainfall and its distribution over the seasons are matters of indifference, except in so far as they may help to determine the type of tree which prevails. A fairly high temperature during the vegetative season is desirable. Great relative humidity of the atmosphere is an advantage, since tall trees expand their crowns at heights where, in comparison with lower levels, the air is hot, dry, and liable to disturbance. But there exist, especially within the tropics, many xerophilous trees which can endure dry air for lengthy periods. Prolonged dry winds discourage the growth of trees; the destructive effect of wind acting in combination with frost in the neighbourhood of the northern tree limit has already been referred to (p. 167).

REQUIREMENTS OF GRASSLAND.—Grasses, which are dominant in the grassland formation, and a number of the subsidiary herbaceous species, are typical shallow-rooted plants. Hence the state of the subsoil may

not materially affect a grassy covering. Frequent rain during the growing period is the most indispensable condition for the good development of turf; but the total rainfall need not be very great, nor is the drying action of winds dangerous during the resting season. For reasons as yet unexplained, the majority of herbaceous grasses do not thrive where the mean temperature is high throughout the year; consequently they are especially characteristic of temperate climates.

CLIMATIC AND EDAPHIC FACTORS COMPARED.—Climatic factors are often nearly uniform over wide areas. On the whole, they are chiefly responsible for the rough outlines in the scheme of the world's vegetation. The finer details are filled in mainly under the influence of *edaphic* factors; that is to say, the various conditions which in their sum total make up the character of the soil.

Where an edaphic factor is very intense, its influence may overrule that of climate to a greater or less extent. The case of swamp vegetation is instructive in this connection. Rainfall should not be an important factor in this instance; and, in point of fact, certain types of swamp vegetation (for instance, reed-brakes) recur in very diverse rain climates. Nevertheless, it happens that the two most marked varieties of swamp vegetation, though in the first place edaphic, are also closely related to climate. Peat bogs occur only in humid districts of temperate and cold countries, partly because there alone the necessary slow decomposition of organic matter takes place. Mangrove swamps, on the other hand, are confined to the humid *tropics* for reasons which are still obscure.

In the sequel it will be convenient to adhere in the main to the arrangement adopted by Schimper. A description of tropical woodland and grassland stands first, supplemented by some account of edaphic formations in the torrid zone, and followed by a shorter treatment of temperate zones upon similar lines. A brief review of deserts, polar zones, and mountain regions completes the survey of land vegetation. Finally, the plant life of the ocean and of fresh water will receive separate discussion.

TROPICAL ZONE—CLIMATE.—The main features of a tropical climate are: high and even temperature, intense illumination, and a very moist atmosphere. The rainfall varies greatly in different districts in amount and distribution. Sometimes a pronounced dry season occupies a part of the year, most often the winter. But the districts of tropical vegetation *par excellence* are those which are perpetually moist and covered by the formation which above all others excels in oecological interest, that is the tropical rain forest. Two notions commonly shape themselves in

the mind of an ordinary observer who is for the first time confronted with the tropical woodland. There is first the idea of a bewildering wealth of forms, to which corresponds the fact that a very large number of species, each represented by relatively few individuals, go to make up the virgin forest; and, secondly, an impression of ceaseless activity, which has a less obvious origin.

It must be specially noted that perennial plants, and particularly the woody forms, possess as definite a periodicity—that is, a regular alternation of resting and working periods—in the tropics as in other zones. In accordance, however, with the equable climate, different functions are in this respect markedly independent of one another; and the seasons at which episodes like the fall of leaves or the shooting of buds take place, vary greatly in different species, in different individuals of the same species, nay, in different branches of one individual. In the Mango Tree (*Mangifera indica*), for example, one or two branch systems may alone be putting forth the reddish-brown young leaves at a time when the rest of the crown retains the dark-green adult foliage; and in the *Amherstia nobilis*, a tree cultivated throughout the tropics on account of its magnificent blossoms, resting buds are interspersed in seeming disorder among shoots in all stages of active growth. Thus, where external conditions are *uninterruptedly* favourable to nutrition, growth, and reproduction, adaptations to the environment, manifold as they may be, do not obscure the fact that outward form and behaviour ultimately depend upon internal governing conditions. In a number of species many physiological processes—especially “growth”—proceed at rates which are far in excess of those recorded for higher plants in temperate zones. A bamboo (*Dendrocalamus* sp.) observed at Buitenzorg by Kraus was found to grow taller by as much as 2 ft. in twenty-four hours, and Haberlandt remarks upon the “fabulous rapidity” of growth in Java of *Albizzia moluccana*, whereby the seedling becomes a tree 20 ft. high in its first season.

The great number of component species is responsible for the very irregular contour of the rain forest when seen from a distance, and for the variegated colour scheme which a closer view reveals. All these features contribute to the impression of “unrest” referred to above. To sum up, individualism is the keynote of the tropical forest as of other luxuriant communities.

RAIN FOREST IN MEXICO.—The plate represents the interior of the tropical rain forest in the province of Chiapas, Southern Mexico. The extraordinary luxuriance and variety of the vegetation is at once apparent. The traveller in such a forest must laboriously cut his way through tangled

undergrowth with machete or billhook. Tree-trunks, rising to heights of 200 ft. and more, are swathed in a drapery of stout liane stems, while their branches are overburdened with woody and herbaceous epiphytes. Most conspicuous among the climbers are Araceæ, with their magnificent foliage, while the forked leaves of *Sarcinanthus utilis* and the trailing sprays of *Marcgravia picta* also attract attention.

The general impression produced upon the beholder is one of unceasing action and fierce competition, especially in the struggle for light.

RAIN FORESTS OF THE AMAZON REGION.—A contrasting note appears to be struck in fig. 187, the original of which is one of the "Physiognomical Plates" that illustrate the vivid descriptions of Brazilian vegetation appended by the famous botanist and traveller von Martius to the well-known *Flora Brasiliensis*. Here the scene is laid in the virgin forest near the River Amazon, under the shadow of three prodigious trees all of one kind. Lesser vegetation, even in the shape of herbs, is almost excluded. Martius describes his feeling on first entering this wonderful forest as resembling the solemn frame of mind in which he would cross the threshold of some magnificent temple. "There was here a heavy darkness and a healthful cold, since tree-trunks of vast girth and height, and with enormous spread of crown, nevertheless formed a canopy so close that hardly any opening remained through which the light of day could penetrate." One monster trunk, 60 ft. in circumference where the buttresses began to die out (some 20 ft. from the ground), rose to so great a height before branching that it was impossible to distinguish the shape of the leaves, and appeared to Martius as it were a "rock endowed with life". This giant was probably more than 2000 years old. The "buttressing" of tall trunks by vertically flattened, planklike roots is a feature not uncommon, notably in members of the families Sterculiaceæ, Moraceæ, and Leguminosæ, in tropical high forests, but rarely occurs outside the latter; its significance is unknown. The smaller tree which is partly visible on the right in the figure (*Eugenia muricata*) is, so Martius judges, not less than 200 years old, and would be considered a large tree in less titanic company.

It must not be supposed that erect palms, two of which appear on the extreme right of the figure, are conspicuous in the rain forest. Generally they play quite a subordinate part, although they may be abundant here and there owing to some local influence. Thus *Mauritia flexuosa* (Burity or Ete Palm) forms groves (Buritisal) on swampy land in the forests of Brazil and Guiana. Other vegetation in the figure includes a (dying) liane in the background, and in front, on the left, tall Maran-

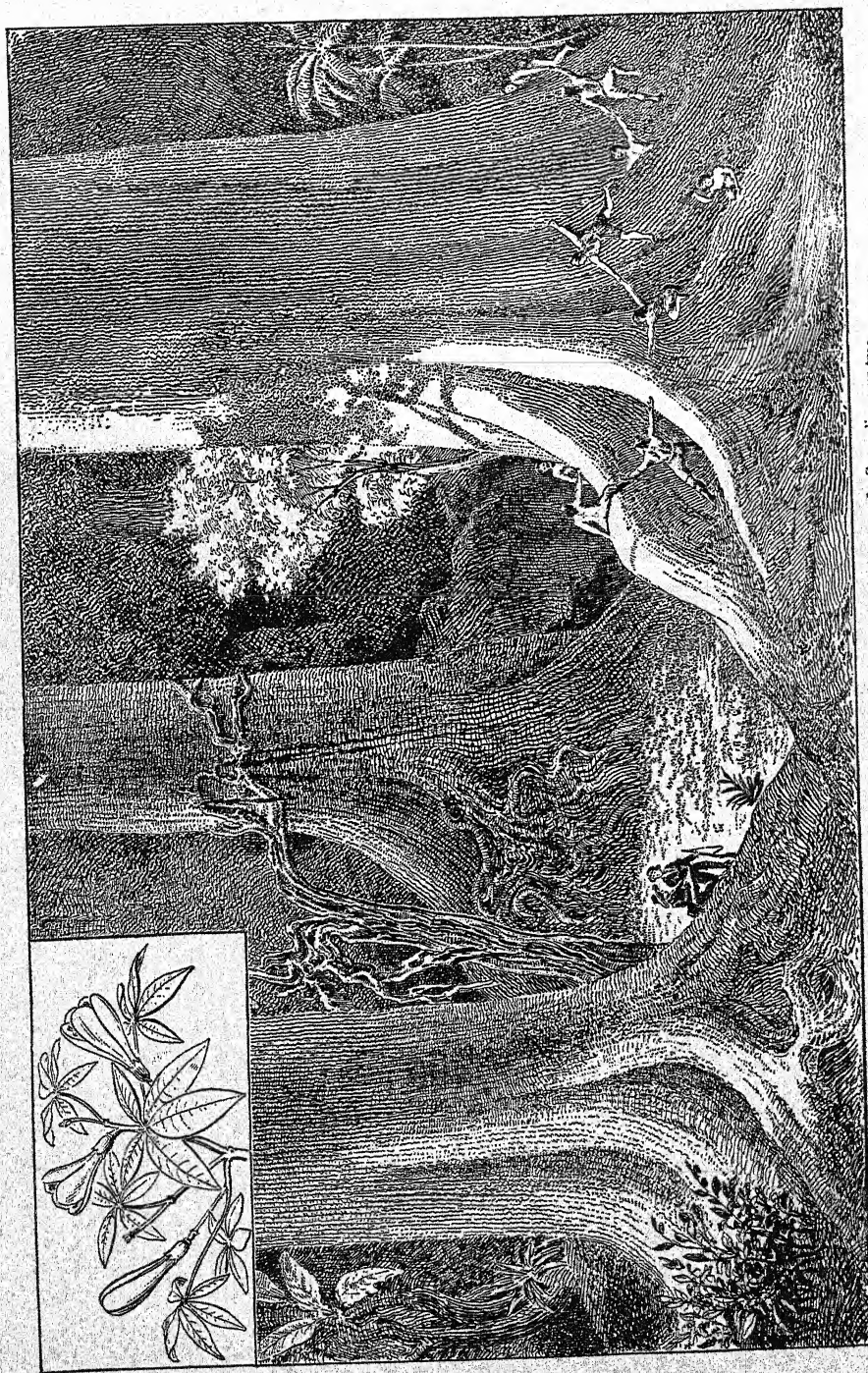


Fig. 187.—Virgin Forest in the Amazon Valley. Foliage and flower of a Sterculiaceae tree
Arborescens ante Christum natum enatae. In silva juxta fluvium Amazonum.

taceous herbs. Various Marantaceæ (arrowroots) and Zingiberaceæ (gingers) are important and conspicuous members of the herbaceous undergrowth in rain forests; they are usually accompanied by brittle-stemmed weeds representing a number of families, and by the Filmy Ferns (*Hymenophyllaceæ*); the latter take in water over the whole surface of their delicate leaves, just like water plants.

In comparing fig. 187 with the plate "Rain Forest in Mexico", it must be noted that other parts of the Amazon forest resemble the Mexican scene, and if anything surpass it in luxuriance. At the spot depicted by Martius an advanced stage of the combat has been reached; a few giants have emerged victorious, and now exercise undisputed sway over the ground below. Similarly the renowned Banyan (*Ficus bengalensis*) of India covers a vast space with the assistance of its pillar roots, and produces so dense a shade that no other plant can exist beneath it. But this method of eliminating competition is comparatively rare, and even the Banyan begins life as an epiphyte, in a state of dependence upon another tree.

Fig. 188 shows a fine specimen of the Jack Tree (*Artocarpus integrifolia*), a native of Indo-Malaya, but here growing in a state of cultivation near Rio de Janeiro. The scanty and irregular branching is a feature which it shares with many trees of the tropics. In higher latitudes the majority of leaf blades are extended more or less horizontally, so as to receive the greatest amount of diffuse light, and overlapping of the foliage is diminished by elaborate branch systems and leaf mosaics. In the tropics, when the leaves are stationary, an obliquely vertical position withdrawing the surface from the most intense insolation prevails, and is often accompanied by a tufting of the leaves at the ends of branches. On the other hand, compound leaves, with extensive powers of movement pertaining to the several leaflets, as well as to the main stalk, are very common (especially so in the family Leguminosæ). In either case a great deal of variety in the behaviour of different regions of the same shoot is permissible, and does, in fact, frequently exist (see p. 175).

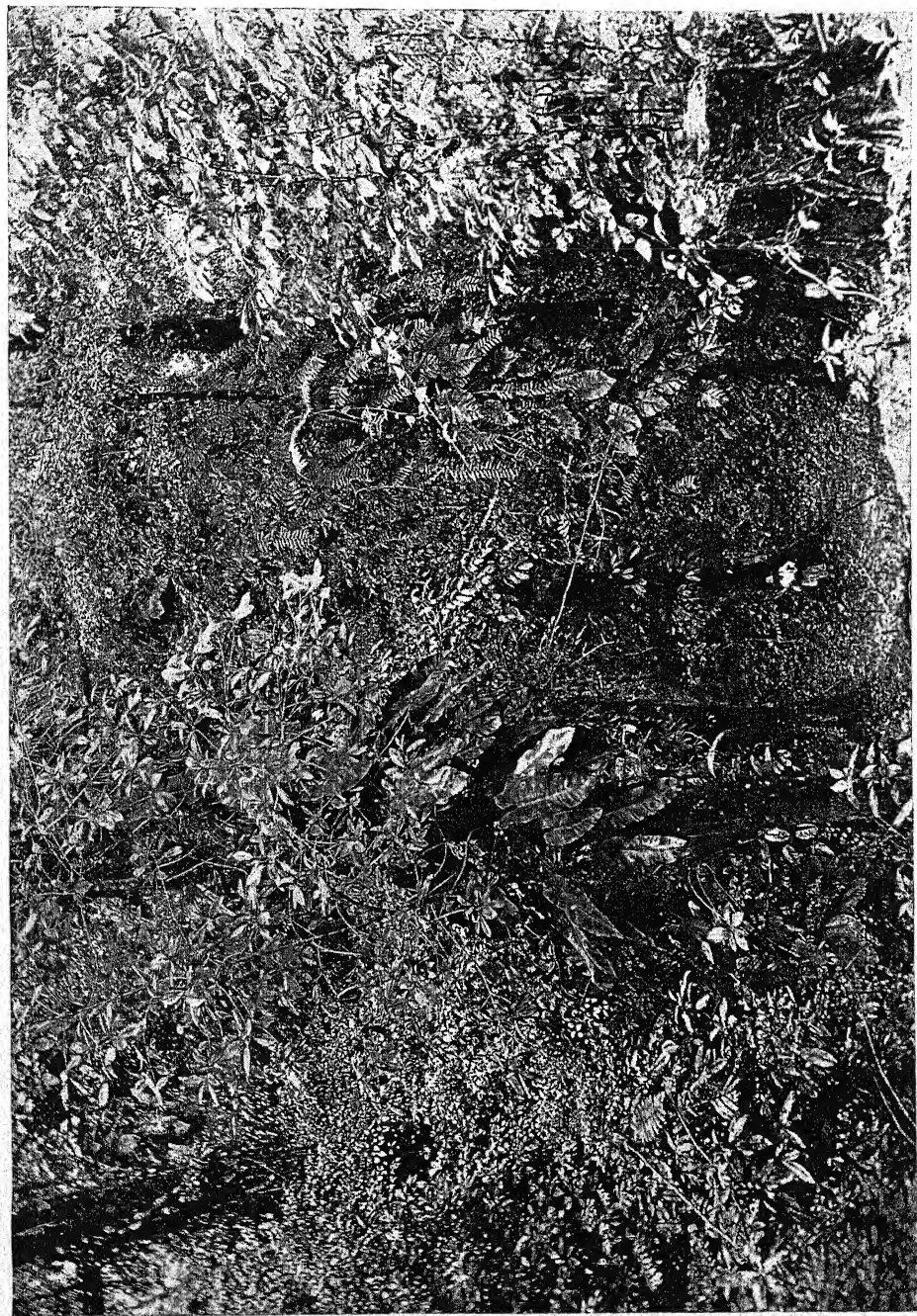
The production of flowers and fruit upon old branches, or even upon the trunk ("cauliflory"), is perhaps, as Haberlandt suggests, the expression of a partition of the shoot into vegetative and reproductive regions.

EPIPHYTES.—The wealth of epiphytes, which is one of the features of the tropical rain forest, is also evident in fig. 188, as far as number of individuals is concerned. In this particular instance the epiphytic flora, partly erect, partly pendent, is very largely composed of orchids, "a host of which wanders about the tree", as Martius writes, storing in tuberous



b, Aroid Climbers.
c, *Marcgravia picta*.

a, A Shrubby Epiphyte.
c, *Sarcocornanthus utilis*.



TROPICAL RAIN FOREST IN SOUTHERN MEXICO

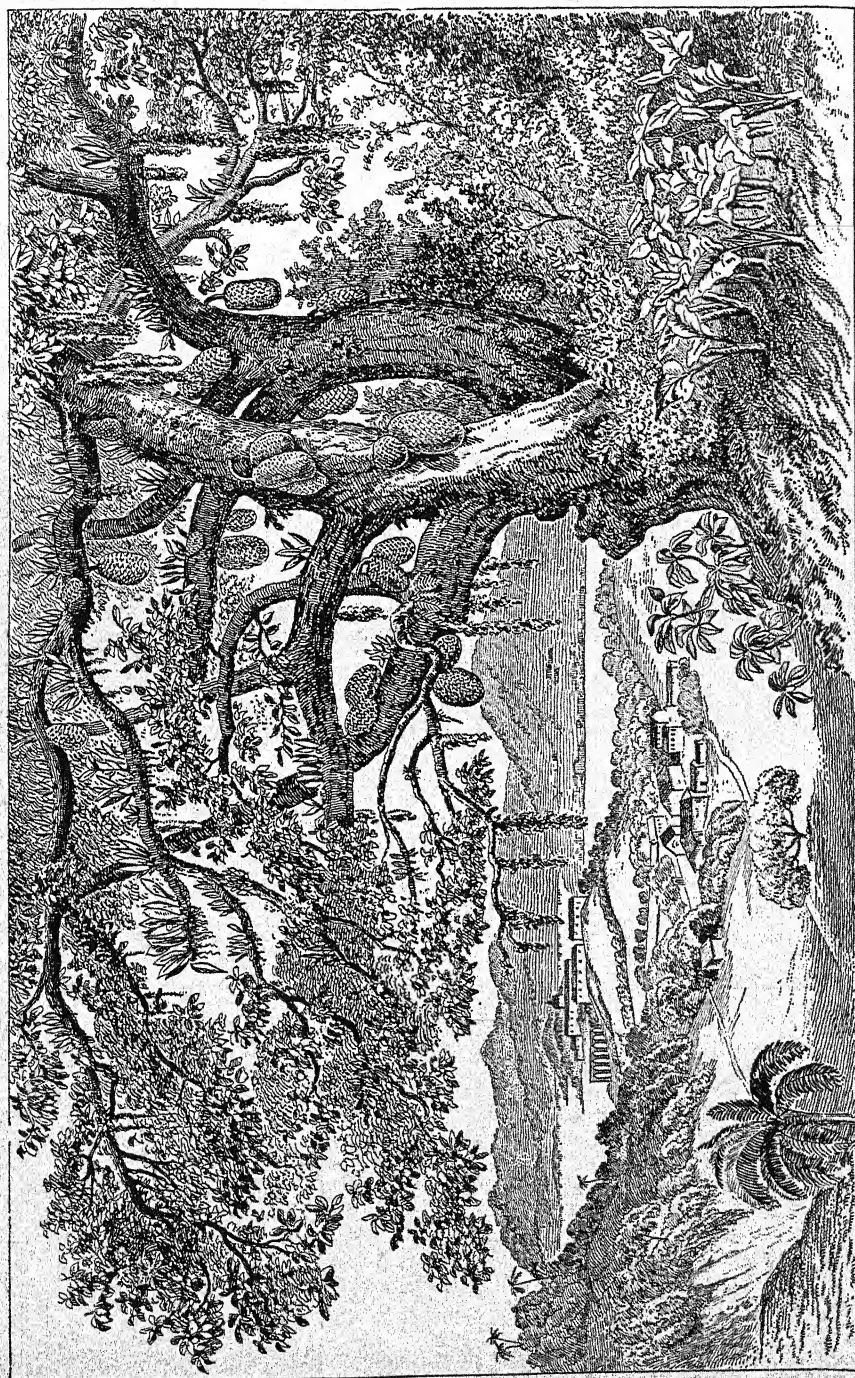


Fig. 188.—Epiphytes upon a Jack Tree near Rio de Janeiro
Artocarpus integrifolia e cultus umbrae. *Sebastiani* sinum et urbem conspicit.

shoots (pseudobulbs) or fleshy leaves every drop of moisture that falls or condenses upon their spongy aerial roots. These roots generally contain some green tissue, in addition to an elaborate water-absorbing apparatus. In the tiny *Tæniophyllum Zollingeri*, indeed, the vegetative organs are practically reduced to a system of bright-green, ribbonlike roots. This species is further of interest as an example of very slow development, therein contrasting strikingly with such a vigorous form as the Bamboo (p. 175), the stem of which, at a rough estimate, grows 2000 times as fast as a *Tæniophyllum* root.

Many epiphytes "trap" water and humus in niches or buckets formed by the special shape and arrangement of the leaves. The fronds of the Bird's Nest Fern (*Asplenium Nidus*), a common epiphyte in the Old World tropics, reach 10 ft. in length, and may enclose a funnel 20 ft. wide from rim to rim. This type reaches its highest level in the Bromeliaceæ, the typical epiphytes of the New World. Here the basal portions of the leaves overlap and fit together so neatly that a watertight tank is formed, the inner wall of which is studded with water-absorbing hairs. In these plants the leaves are responsible for the whole intake of material, while the roots serve purely as fixing organs.

In the case of *Tillandsia usneoides* (see fig. 188) the whole plant consists of leafless, stringlike branching shoots covered all over with absorbent hairs. Roots are entirely absent, and hanging freely suspended by its encircling branches the plant resembles, as its specific name implies, a lichen rather than an ordinary flowering plant. It is continually dispersed, not only by wind, but also by birds, which find the horsehair-like substance useful for nest-building; as it further suffers drying up with indifference, its abundance throughout the American tropics and in certain adjacent subtropical districts (Florida, &c.) is readily understood.

ECONOMIC PLANTS.—It is not an easy matter to fit economic species into any scheme of natural vegetation, because the great majority of such species exist solely in a state of cultivation. Now the average cultivated plant is disproportionately adapted to a single factor, namely, the human standard of usefulness; it is as it were an œcological monstrosity, and hence particularly eludes the attempt to incorporate it in an œcological scheme. Human interference, however, does not subordinate all other factors to an equal extent; thus the regulation of climate as a whole has so far been attempted on a limited scale only, although irrigation as a means of supplementing deficient rainfall is already extensively practised. Further, some species seem to be far more exacting in their requirements than others, and those at least may sometimes be referred to a

natural vegetation type without risk of serious error, while the remainder are most conveniently grouped in relation to the "broadest" factor, namely temperature.

The tropical economic species which thrive best in a rain-forest climate comprise, among others, most of the trees and lianes which yield rubber (for instance, *Hevea brasiliensis* (= *Siphonia elastica*), the source of Pará rubber); the trees (*Eugenia caryophyllata*, cloves; *Cinnamomum zeylanicum*,

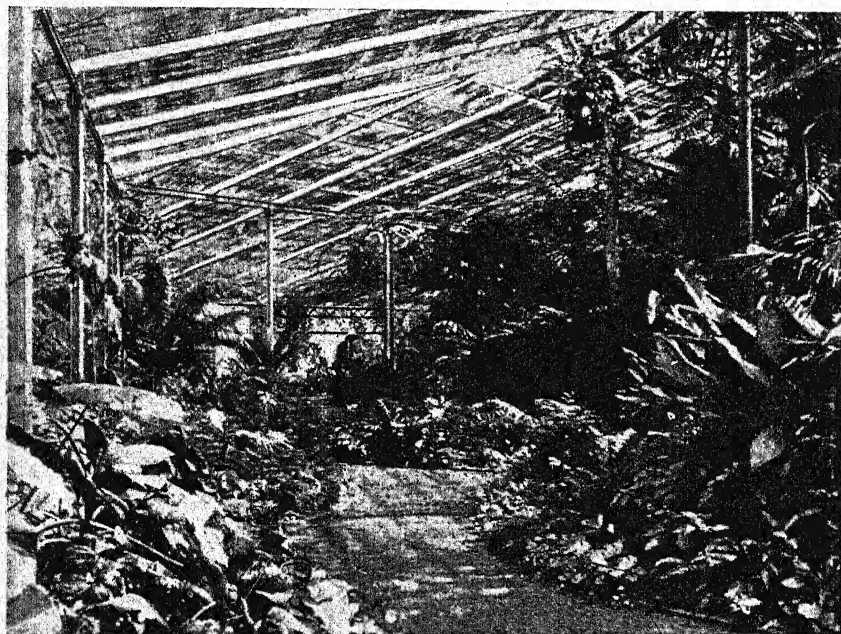


Fig. 189.—The "Orchid House" in the Royal Botanic Gardens at Sibpur (Calcutta)
(Photograph by Mr. Lane, Curator of the Gardens)

This is a house only in the horticultural sense. Walls and roof are covered in, not with glass, but with a network of coir cordage, upon which the more hardy epiphytes and climbers grow. In this way shade and shelter are provided for hygrophilous orchids and ferns and other inhabitants of the rain forest, for which the open-air conditions in Calcutta are not sufficiently equable.

cinnamon; *Myristica fragrans*, nutmeg and mace; *Pimenta officinalis*, allspice), and herbs (*Piper* spp., pepper; *Vanilla planifolia*, vanilla; *Zingiber officinale*, ginger; *Elettaria* spp., *Amomum* spp., cardamoms) furnishing the principal spices; and the Cacao tree (*Theobroma Cacao*).

Breadfruit (*Artocarpus incisa*), cassava (*Manihot utilissima* and *M. Aipi*), taro (*Colocasia* spp.), and sago palms (*Metroxylon* spp.) are important food plants, though more as local staples than in a commercial sense. Oil palm (*Elæis guineensis*) and earthnut (*Arachis hypogæa*) among other species yield useful oils.

Well-known timbers are derived from *Swietenia Mahagoni* (mahogany), *Diospyros* spp. (ebony), *Nectandra* sp. (greenheart), and *Dimorphandra Mora* (mora).

Further characteristic products are dyewoods, such as logwood (*Hæmatoxylon campechianum*), redwoods (various *Cæsalpinieæ*), and old fustic (*Chlorophora tinctoria*); the valuable fibre Manila hemp (*Musa textilis*); certain drugs (*Strychnos Nux-vomica*, the source of strychnine; *Cola* spp., nuts rich in caffeine and theobromine); and numerous delicious fruits (*Mangifera indica*, mango; *Psidium Guava*, guava; *Garcinia Mangostana*, mangosteen; *Anona* spp., custard apples; *Durio zibethinus*, durian).

RAIN FOREST, MONSOON FOREST, AND THORN FOREST.—Rain forest covers a comparatively small area in the tropics, flourishing especially near the sea (see Chart). Wherever a dry season recurs at least once every year, but the climate is otherwise favourable to woodland, there less luxuriant types of forest (monsoon forest and thorn forest) prevail.

CATINGAS.—The catingas of Brazil illustrate the thorn forest formation which is frequent in South America and the Antilles, especially on limestone soil (see fig. 190). Here the majority of species, woody or otherwise, possess remarkable arrangements for water storage. The bloated trunks of Barrel Trees (*Cavanillesia arborea*) contain abnormally soft and sappy wood. *Spondias tuberosa* buries its swollen roots—which are frequently dug up by thirsty travellers for the sake of the water hidden in the hollow interior—far below the parched surface of the ground. Succulent cacti (*Cereus Jamacaru*, etc.), armed with formidable prickles, in many cases reach treelike dimensions, but also in numerous smaller forms (spp. of *Opuntia* and *Melocactus*) fill the rôle of undergrowth. Lianes, however, are not absent; and xerophilous epiphytes (especially *Bromeliaceæ*) are rather abundant. In time of drought (which here may last several years) the catinga presents a forbidding aspect, and is with reason shunned by the inhabitants of the neighbourhood. A shower of rain may transform the scene as if by magic. Buds which have waited months, and perhaps years, for this event burst forth in the course of twenty-four hours.

TROPICAL SAVANNA.—Tropical grassland generally takes the form of savanna. Under special conditions the grass may rise to a height of 20 ft., and crowd together to form an almost impenetrable jungle; but generally it is about 6 ft. high, and grows in tufts separated by patches of bare soil. Characteristic is the presence of scattered trees of moderate size; some of these have crowns of peculiar forms, and may be variously termed "umbrella trees" (*Acacia planifrons*), "pagoda trees" (*Eriodendron* spp.),

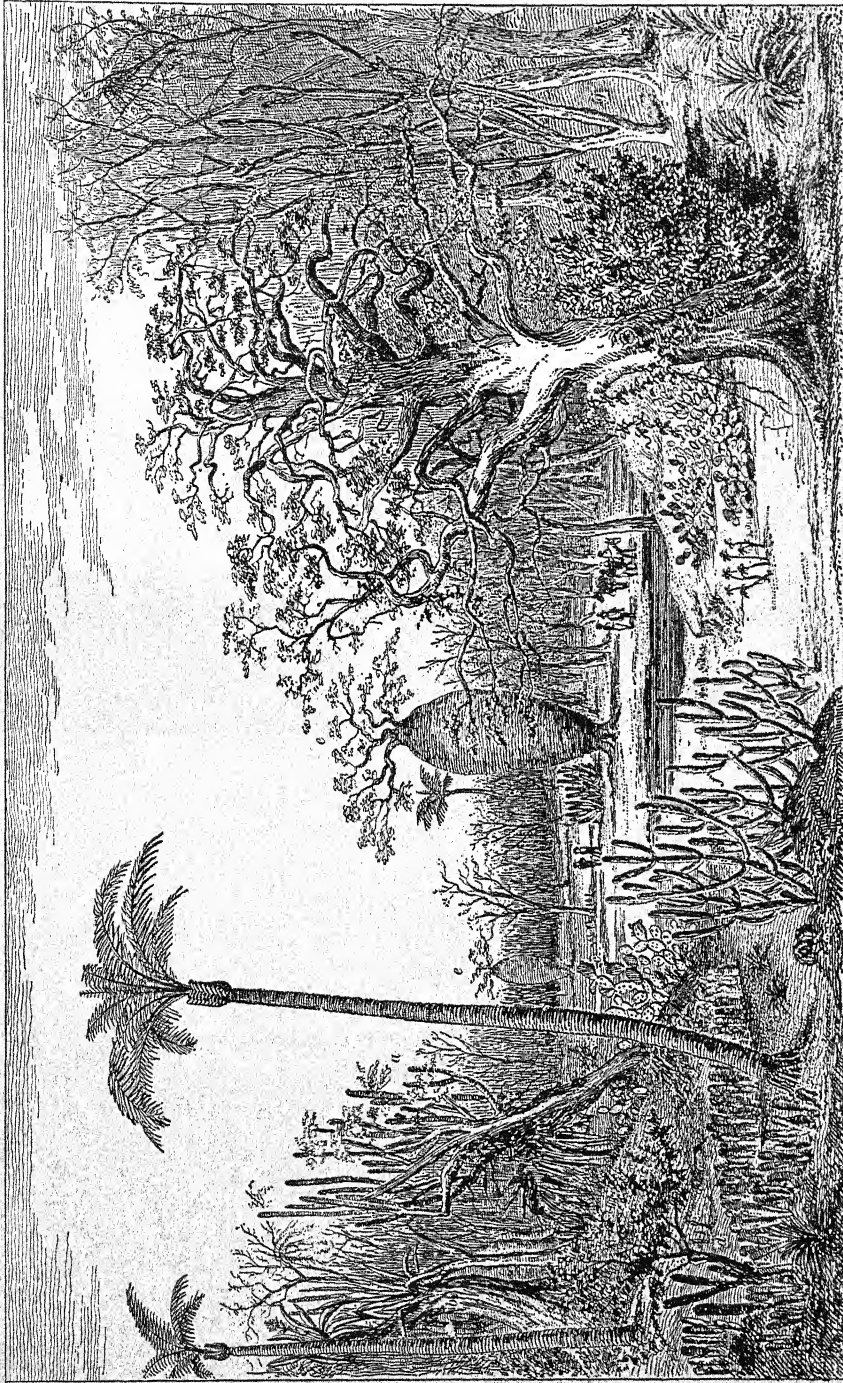


Fig. 190.—The Brazilian Catinga

Silva aestu aphylla, quam dicunt Cae-tinga, in provincie Bahiensis deserto australi.

a. *Cereus Janacaru.* *b.* Epiphytic Bromeliaceae. *c.* *Opuntias* (Cacti). *d.* *Melocactus.* *e.* *Cavendishia arborea.* *f.* *Cereus geometricus.* *g.* *C. hexagonus.* *h.* Terrestrial Bromeliaceae.

or "candelabrum trees" (Cacti in America; *Euphorbia* spp., *Hyphaene* spp., in Africa). Other woody species attain large or even huge dimensions. A notable example is the African Baobab (*Adansonia digitata*), which, though not of great height, ranks amongst the bulkiest of trees. The monstrous trunk—sometimes 30 ft. in diameter—and the very stout branches are surprisingly soft and sappy and contain an abundant reserve of water against the dry season, during which period the tree is moreover leafless. The Baobab can, in fact, exist equally well on very dry soil and on almost marshy land, but an open unhampered position is essential to its welfare.

More or less typical savanna covers the greater part of the interior of tropical Africa and wide tracts in South America, such as the Savannas of Guiana, the Llanos of Venezuela, and the Campos of Brazil.

EDAPHIC FORMATIONS IN THE TROPICS—MANGROVES.—In the rain forest variations of the soil appear to be of slight importance in comparison with the potent influence of constant humidity and even temperature. But even there the character of the soil has some share in determining the type of vegetation (see reference to palms, p. 176), and the influence of such conditions increases in periodically dry districts where limestones, laterites, and other peculiar soils harbour special floras. It is on the seashore, however, that the most remarkable of all tropical local formations is found.

The Mangrove swamp or Tidal Forest, which occupies sheltered tracts of the coast in humid districts of both hemispheres, reaching its most luxuriant development on muddy lagoons, creeks, or estuaries, especially in the Indo-Malayan region, is noteworthy in so many respects as to merit detailed notice. On temperate coasts only herbaceous members of the land flora venture out into actual contact with the sea; whereas the most essential constituents of the Mangrove swamp are trees and bushes comprising only a small number of species (especially *Rhizophora mucronata*, *R. Mangle*, *Avicennia officinalis*, *Bruguiera gymnorhiza*, *Sonneratia acida*), but representing several families not very nearly related to one another.

For a typical Mangrove, such as *Rhizophora mucronata* (fig. 191), the chief problems to be solved are: resistance to the ebb and flow of the tide over a muddy bottom; extraction of sufficient water from varying mixtures of salt and fresh water, or from pure sea water; proper aeration of the parts embedded in the mud; and safe anchoring of the young plants. *Rhizophora mucronata* does, in fact, solve these problems in so satisfactory a manner that it is able in favourable situations to reclaim an appreciable amount of land from the sea. The intricate system of flying

buttress or stilt roots is admirably contrived to resist the insidious assaults of the water. The xerophilous character of the foliage, typical of Mangroves, by reducing transpiration permits of a low rate of absorption;

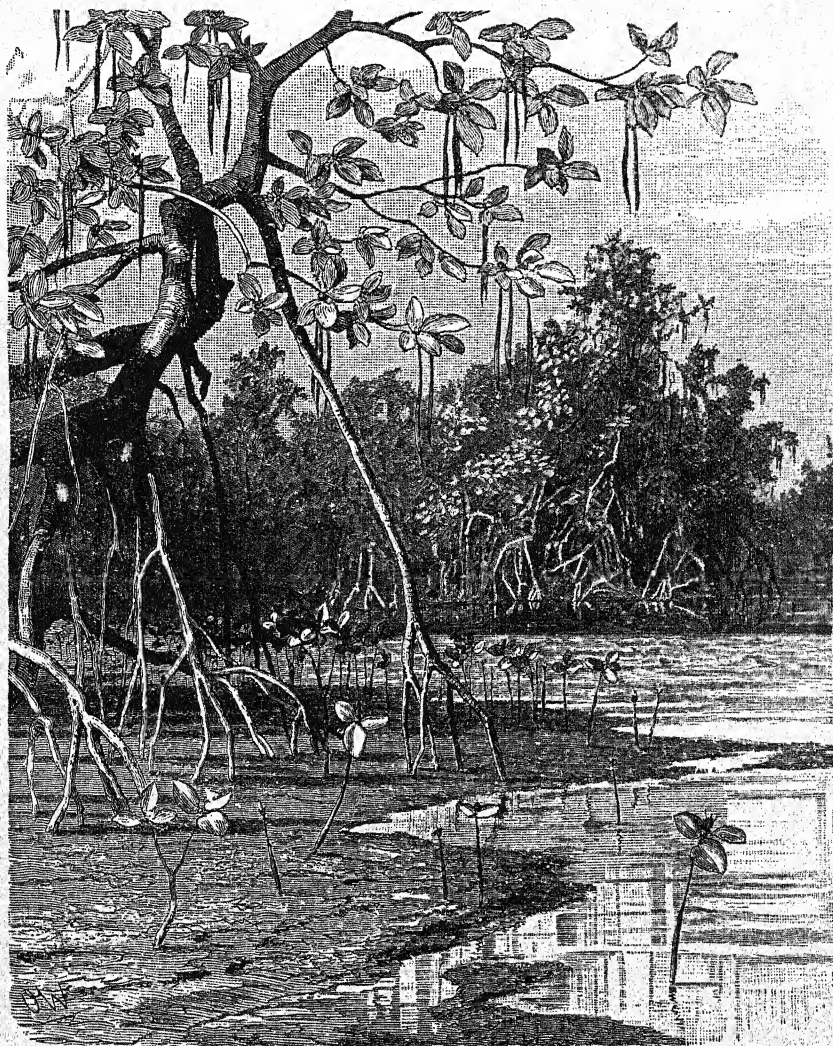


Fig. 191.—Mangroves near Goa, on the West Coast of India, at ebb tide.

moreover, a special tissue in the leaves acts as a reservoir of water, upon which particularly the young growing shoots can draw. As common salt is known to have a harmful effect upon most land plants, if it accumulates beyond a certain concentration in the cells, a small intake of water must be of advantage to a terrestrial species which is trying to grow in sea water.

Ventilation of the embedded roots is ensured in a manner which is fundamentally the same for all Mangroves though varied in detail. Part of the root region is aerial, and is so constructed that active gas-exchange takes place between the outer air and a well-developed system of internal spaces. A very elaborate aerating apparatus is present in *Sonneratia acida*. Here there emerge from the mud innumerable upward-growing rootlets, with a very peculiar structure which more than any other plant organ recalls the breathing arrangements of mammals; for movements of the surrounding water cause alternate expansion and contraction of the spongy tissues which largely compose these roots, and so produce an indraught of the outer air or expulsion of the enclosed gases.

The well-known "vivipary" of Mangroves consists in a precocious development of the embryo into a hanging, usually cigar- or torpedo-shaped seedling which protrudes from the (physically) lower end of the fruit while the latter remains attached to the tree. After growing to a considerable length the seedling drops off, its heavy pointed end penetrating the mud and rooting firmly in a few hours; if the young plant on falling encounters water of sufficient depth to prevent this immediate planting, it floats in an upright posture and may sink into the ooze close by as the tide recedes, or may drift away and settle elsewhere.

ECONOMIC PLANTS.—Two features characteristic of many cultivated plants, namely an extensive geographical range and the existence of a great number of races often disguised under a single name—features, be it noted, not unconnected with one another—add to the difficulty of displaying economic species to advantage in an œcological setting (p. 180). To what climatic or edaphic formation, for instance, is rice to be assigned, since literally thousands of distinct races of this cereal are grown, many requiring temporary inundation, a few thriving on permanently dry land, some flourishing in tropical forest clearings, others ripening in the valley of the Po? Evidently reasons abound for attempting no more here than an enumeration of the principal useful plants under certain heads, immediate attention being confined to species which are mainly tropical or subtropical.

Rice (*Oryza sativa*) stands easily first in importance, feeding as it does nearly one-half of the human race. Millets (spp. of *Panicum*, *Sorghum*, and *Pennisetum*) are locally indispensable. Yams (*Dioscorea* spp.) and sweet potato (*Ipomœa Batatas*) correspond to our potato, and soy bean (*Glycine hispida*) and lentil (*Ervum Lens*) to the temperate pulses (peas and beans), while garlic (*Allium sativum*) similarly replaces onion. Bananas and plantains (*Musa sapientum*) are noteworthy, not so much

for their nutritive value as for their enormous productive capacity (a hundredfold that of wheat).

Sugar cane (*Saccharum officinarum*) yields two-fifths of the world's supply of sugar; tobacco (*Nicotiana* spp.) requires no comment, and the same is true of cotton (*Gossypium* spp.); other fibres are jute (*Corchorus* spp.) and ramie (*Bœhmeria* spp.). Hemp (*Cannabis sativa*) is not grown for fibre in hot countries, but its narcotic resin (churrus) or preparations containing the active principle (bhang, gunja) are smoked or imbibed by Asiatics. Drugs further include opium (*Papaver somniferum*), senna (*Cassia* spp.), and coca leaves (*Erythroxylon Coca*).

The chief timbers are teak (*Tectona grandis*), rosewood (*Dalbergia* spp.), satinwood (*Chloroxylon Swietenia*), and the cigar-box "cedars" (*Cedrela* spp.). Among fruits, pineapple (*Ananas sativa*), oranges, lemons, limes, and other species of Citrus deserve notice. Mention may also be made of Panama (*Castilloa elastica*) and Assam (*Ficus elastica*) rubbers, which can to some extent resist respectively drought and cold; of the oil producers, *Sesamum indicum* (sesame) and *Ricinus communis* (castor oil); and finally, of a number of palms (Palmyra, Talipot, &c.) and the Bamboo, the uses of which are legion. Among the palms the Coco Palm (*Cocos nucifera*), apart from its commercial value (as yielding copra and coir) and its many local applications, is œcologically interesting as a typical instance of a shore plant, which is wonderfully adapted for transport by ocean currents and for establishment of the seedling on the beach.